Cost Benefit Analysis for Flexibility Services

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Summary

Cyprus has an isolated power generation system that nowadays strongly depends on heavy fuel oil and diesel exports for electricity generation. Nevertheless, the Cypriot government is steadily working on following their National Action Plan to achieve a more sustainable and safer energy system in the island. With the support of EU investments, this National Action Plan aims to increase to 16% by 2020 and to 23% by 2030 the share of renewables. Furthermore, the finding of Natural Gas reserves in Cyprus has played a strong role in the future planning, leading a transition to move from oil-fired to natural gas-fired power generation. At the same time, the potential of the coming projects ′EuroAsia Interconnector′ and the ′EastMed Pipeline′ in 2023 will put an end to the energy isolation of the island, as well as boost the security of Cyprus' energy system and diversify its electricity mix.

The primary aim of this project is to investigate the current energy storage technologies available, its maturity, different technical features and applications. With this and a set up of different future scenarios, a study of the cost benefit relation of the deployment of these different technologies will be carried out.

The study analysis 6 different possible Energy Storage Technologies for Cyprus 2040 and based on the uncertainty of the Capital Cost three different scenarios were set: an optimistic, the expected and the pessimistic.All the scenarios the prmisse of a penetration of renewables of 65% and a use of the ′EuroAsia interconnector′ of 15% of its capacity.

The results of the study proved that there is a significant potential for renewables. In all the different scenarios was possible to observe a significant growth in both solar and wind electricity generation. Furthermore, the presence of the different energy storage technologies turned out to be a key element to allow the penetration of renewables in all the different scenarios.

Introduction

It is an unquestionable truth that the worldâs population has been constantly increasing over time, but it is also an undeniable reality that this growth has exponentially increased its pace the very last centuries. The 1600s population was around 0.5 million, and in 200 years, during the 1800s, it doubled up to 1 million, but after 200 years more, the figure has multiplied almost 8 times. This growth has of course come alongside with an as-rapid growth of consumption.

A crucial revolution that has had a deep impact on these recent changes has been electrification. This trend has enabled development, as for example a lack of modern lighting in households is believed to limit their possibilities to pursue not only productive activities after nightfall, but also educational and recreational activities. Likewise, enterprise development and the provision of public services like health care and schooling are difficult [1]. There is however, a mismatch between the pace of population growth and the adaptation speed of electricity generation. The use of fossil fuels like coal or oil have barely decreased over the last decades, accounting for around 60% of the electricity production. Coal-fired electricity generation alone accounted for 30% of global CO2 emissions last year.

Therefore, there is an imperative need of a shift towards a more sustainable and safe energy generation (EG) system, with which all countries can contribute to achieve the Paris Agreement and set a global framework to avoid dangerous climate change and limit global warming to below 2Â°C and pursuing efforts to limit it to 1.5Â°C. For this shift to happen all countries must acknowledge the available resources as well as the physical constraints to be able to build a suitable and efficient generation system. One of the most peculiar cases to be studied are islands, as their systems are most of the times isolated and traditionally experiencing difficulties in terms of energy supply and energy security associated with an important dependency on imported fossil fuels [2].

In Europe, the island with the highest share of fossil fuel dependency is Cyprus. Cypriots spend over 8% of their GDP to cover the costs of fossil fuel imports, which have experienced an increase of 41% since the 1990s. However, as the rest of the countries, Cyprus has to implement the necessary measures to meet the European obligations on climate and energy, and reaching high shares from renewables can be a potential solution. The renewable energy sources goal for electrical power production for 2020 is 16% according to the National Action Plan, and 23% by 2030 [3].

The most attractive renewable energy technology is solar PV, since the solar radiation in the island is abundant. Nevertheless, an increasing penetration of renewables can result in important grid instability and operational problems. The priority access to the grid of electricity produced by the installed wind and PV power plants together with the low power required during specific periods of the year, can arise operational issues to the Cyprus grid. This renewableâs secondary effects could be corrected with the deployment of energy storage.

The primary aim of this project is to research and investigate the current energy storage technologies available, its maturity, different technical features and applications, to be able to later understand which ones are better suited to be used in the Cyprus energy system, and study the cost benefit relation of its deployment.

The first objective is to analyse and study the future plans and actions that are going to be completed for electrical power generation in Cyprus by evaluating the National Energy and Climate Plan for 2030, to better understand where the governmental politics are focusing, and to which scenario the country is moving towards in the coming decades.

The second objective is to replicate the 2040 planned scenario using Homer Pro, the global standard for simulating and optimizing micro-grid designs, and run 3 simulations with different pairs of energy storage technologies varying the Capital Cost of each according to the uncertainty of its price in 2040. With this, an analysis and evaluation will be carried out to conclude which possible alternative futures Cyprus could consider to continue its journey towards a cleaner, safer and fare energy system.

Acknowledgements

I would like to first thank Andreas Sumper, my thesis supervisor for the help, support and knowledge, and for the guidance along these past months. It was crucial to guide me through some moments of doubt regarding the path that should be followed

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Chapter 1

State of the Art

Throughout the years electrical energy generation has significantly changed, not only the amount that needs to be generated as well as the type of technology used. Since the beginning of mass electricity generation the primary resource to produce that energy were mainly fossil fuels. However, as the process of electricity production became more and more mature the first steps towards introduction of new forms of energy were made.

Energies from renewable sources started to be introduced in the â, when the need of a transition to a cleaner energy system slowly started to emerge. Nevertheless, the increasing penetration of renewables in the grid throughout the world, has raised different issues.

In spite of these real barriers, renewables are a key element when it comes to climate change. The use of Green House Gas (GHG)-free energy is extremely important to meet the global goals of the Paris Agreement.

The crucial role of renewable energies and its continuous deployment growth together with these technical obstacles, lead inevitably to a clear conclusion: the use of energy storage is and will be essential to achieve a reliable energy system. It is through energy storage that is possible to do load levelling and peak shaving, frequency regulation, damping energy oscillations, and improving power quality and reliability.

There are several types of energy storage as it will be shown in this chapter. Besides the type, the different technologies can also be categorized according to its application. This categorization depends mainly on two variables the storage energy density and the power density. The storage density is the energy accumulated per unit volume or mass. As for the power density, it is the energy transfer rate per unit volume or mass [4]. Energy storage can also be classified based on the duration of the storage. Long term storage is generally characterized by storing energy from a few months up to a season, whereas short term involves the storage of energy from hours to days [4].

1.1 Mechanical Energy Storage

1.1.1 Pumped Hydro Energy Storage (PHES)

This is a well-established technology with a long history that results in a high technical maturity as well as a large energy capacity. PHES stores energy in the form of potential energy to whenever it is required transform into kinetic energy. As illustrated in figure 1.1, a simplification of the system, there are two reservoirs connected that during off peak hours and through an electric pump transfer the water from the lower reservoir to the one in the highest position. Once a certain amount of water has been pumped it is possible to use whenever is required the system to produce electricity. This system will transform the potential energy in the upper reservoir into kinetic energy. This kinetic energy induces a rotation into a turbine which will discharge this energy into a generator to which is connected to. The rated power in PHES depends on both flow rate and water pressure through the turbines and rated power of the pump/turbine and generator/motor units [5].

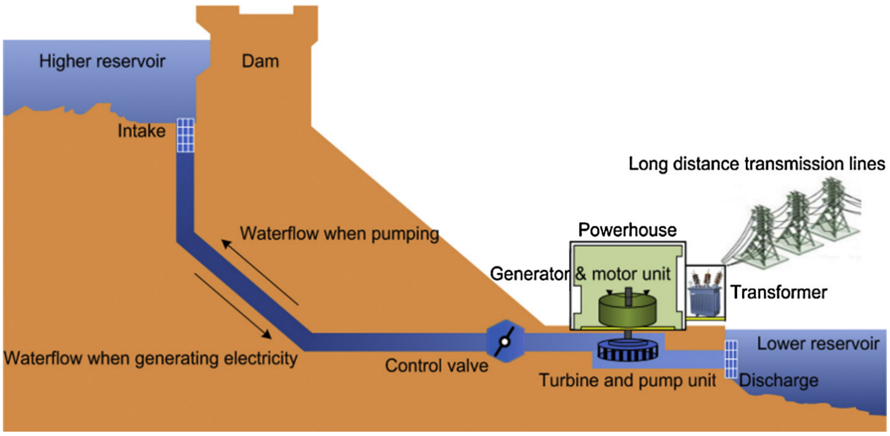

Figure 1.1: PHES System [6]

This technology is utilized to perform time shifting, frequency control non spinning reserve and supply reserve.

PHES is characterized by its high efficiency from 70% to 80% and large capacity 1000 â 1500 MW [7]. Furthermore, it has low operation and maintenance costs. However, it has a high initial investment as well as a long construction period and its construction is limited by the topography of the terrain. PHES also have a significant impact in the local ecosystems.

1.1.2 Compressed Air Energy Storage (CAES)

CAES is another technology capable of providing 100 MW capacity from a single unit. This technology makes use of the low demand, when there is electricity surplus to drive a reversible motor/generator unit to activate compressors that will inject pressurized air into a storage vessel. As a result, the energy is stored as pressurized air. The inverse process occurs when the power generation does not meet the load demand. The stored air is discharged and heated which can come from either the heat recovered from the compression process or combustion of fossil fuels. Once the air is heated it finally reaches the turbines as illustreted in figure 1.2. In order to improve the overall efficiency of the process the waste heat from the exhaust should be recycled by a recuperator unit.

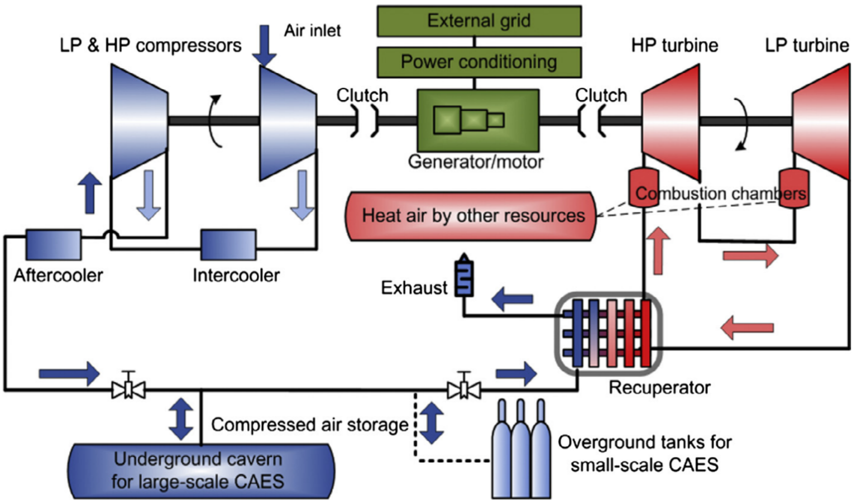

Figure 1.2: CAES System [6]

CAES technology can be built both in small and large scales. However, this is one of the most expressive examples where the scale of the project reduces dramatically the cost per kWh. Furthermore, the technology provides moderate speeds of response as well as good partial-load performance. In the case of a large scale CAES its applications are load shifting, peak shaving and frequency and voltage control [6].

1.1.3 Flywheel Energy Storage (FES)

Flywheel energy storage is also known as kinetic energy storage. This technology is mainly formed by: a flywheel, a group of bearing, a reversible electrical motor/generator, a power electronic unit and a vacuum chamber [8].

FES working principle depends on the acceleration or deceleration of the flywheel that, depending on the movement will store or provide electricity respectively. This energy is transferred to or from the flywheel through an integrated motor/generator. In order to avoid any air resistance and consequently optimize the rotation of the flywheel the system is paced in a high vacuum environment as illustrated in figure 1.3. The amount of energy stored depends on characteristics of the flywheel such as inertia as well as its rotating speed.

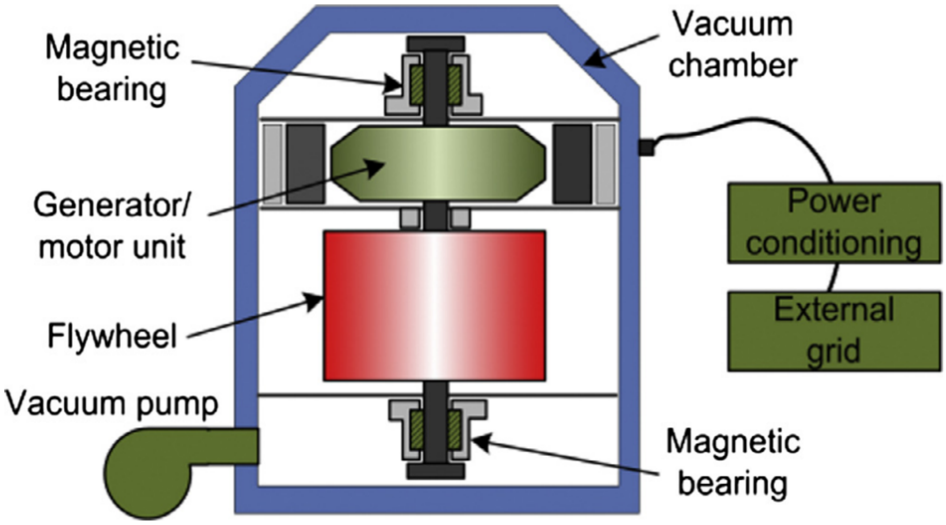

Figure 1.3: FES System [6]

FES can be classified as low speed FES using steel as its material and rotating below 6000 rpm or as high-speed FER using composite materials which can rotate up to 10000 rpm [9]. As for the application the low rotating speed flywheels are typically used for short-term and for medium-high power applications. The high rotating flywheels are mainly used in power equality and ride through power service in traction [10].

The favourable characteristics of FES are a high cycle efficiency of around 95%, relatively high-power density, no depth-of-discharge effects and easy maintenance [8, 9, 11]. However, these devices suffer from idling losses during the time when the flywheel is on standby. This can lead to a relatively high self-discharge, up to 20% of stored capacity per hour [11].

1.2 Electrochemical Energy Storage

1.2.1 Battery Energy Storage (BES)

BES is a very well known technology that is present in both our daily life as well as the industry's. A BES are eletrochemical cells connected either in parallel or in series, from which electricity is produced with a certain voltage from an electrochemical reaction as shown in figure 1.4. For this reaction to occur each cell needs to have two electrodes (one anode and one cathode) with an electrolyte that can either be solid, liquid or in a viscuos state [12,13]. As a result, whenever this technology is providing energy electrochemical reactions are occurring both at the anode and at the cathode that will provide to the external circuit electrons on the anodes side which will be collected on the cathode side. In order to recharge the inverse process occurs and the battery is recharged by applying an external voltage to both electrodes as illustrated in the figure 1.4.

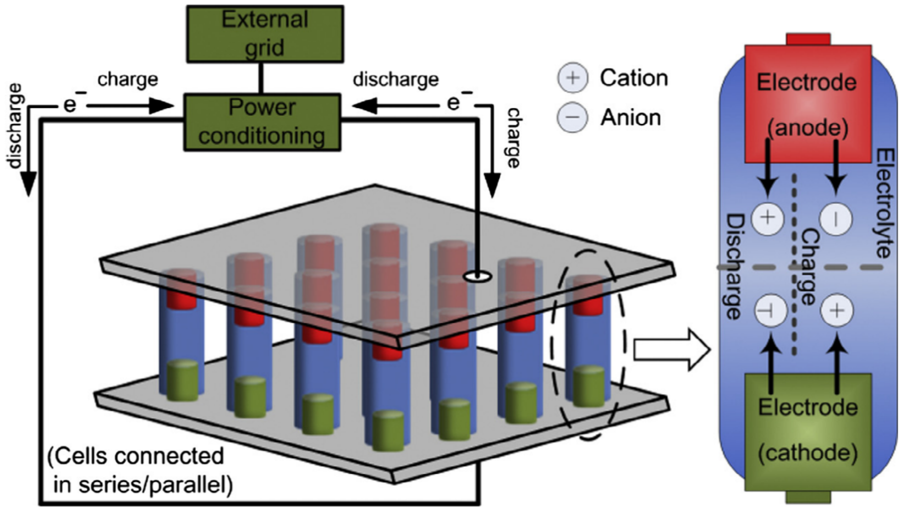

Figure 1.4: BES System [6]

BES technology is characterized by having multiple reactions that can occur within the cell with different chemical element. However in this thesis only the most relevant will be discussed.

Lead-acid Batteries

This type of chemical reaction is widely spread across the globe through the well known rechargeable batteries [14, 15](4,10). In this reaction the anode is made of Pb (Lead) and the cathode of PbO_2 (Lead Dioxide) while the electrolyte is H_2SO_4 (Sulfuric Acid).

Lead-acid batteries are characterized by having fast response times, good efficiencies between 63%-90%, small daily self discharge rates (<0,3%) and low Capital Costs (CC) (50-600 $/kWh) [11, 14, 16, 17]. Despite having all these advantages, the low cycling times (around 2000), the energy density (50-90 Wh/L) and specific energy (25-50 Wh/kg) make their applications limited in utility scale [14, 18, 19]. Furthermore, the applications of this type of energy storage need to take into consideration the operating temperatures as they perform poorly in such conditions. As a result, to be used, the system needs to be over dimensioned which might increase significantly the cost.

Lithium-ion (Li-ion) Batteries

This technology of BES uses lithium metal oxide as a cathode and an anode of graphitic carbon, as for the electrolyte is usually a non-aqueous organic liquid containing dissolved lithium salts, such as $LiClO_4$.

Lithium-ion is one of the most acclaimed technologies in the industry due to its high energy density (160-200 Wh/kg) [6, 19](9,77), fast response time (in the order of milliseconds), low self-discharge rate and high efficiency (around 97%) [6, 20]. However, the lifetime and the depth of discharge are both dependant on temperature. Moreover, aging is emphasized by high temperature [11, 14, 21]. This technology has an Forecasted Operation and Maintenance (FOM) cost of 2,5% of the initial investment [22].

There is significant on going research surrounding this technology due to its various applications and the all the characteristics mentioned above. One of the most promising is Lithium-air due to its high energy density as shown in the figure 1.5 which competes directly with Gasoline [4]. However, some challenges still need to be addressed before this technology can be commercialized.

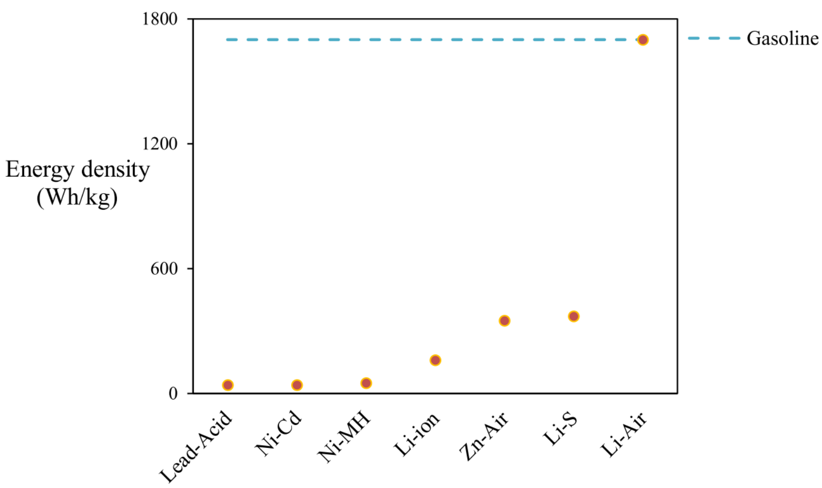

Figure 1.5: Batteries Energy Densities [4]

Nickel-cadmium (NiCd) Batteries

This type of battery has nickel hydroxide and metallic cadmium as electrodes and an alkali aqueous solution as electrolyte. This technology is considerably reliable and has low FOM costs. However, its growing weakness are the environmentally hazardous materials elements required for the operation of this type of batteries, Cadium and Nickel which are considered toxic heavy metals [23, 24].

Nickel-Cadmium has a cycle efficiency of 60%-90% and a lifetime of 300-10^4 cycles [25]. From the financial point of view NiCd has a capital cost of 1500-5000 ($/kW) and 800-1500 ($/kWh) [14].

Molten Salt Batteries

This class of batteries uses molten salts as electrolytes and the most well known types are NaS (Sodium-Sulfur) and $NaAlCl_4$ (Sodium Tetrachloroaluminate) or also known as ZEBRA batteries. This type of batteries makes use of high temperatures to melt its electrodes leading to high reactivity.

Sodium-sulfur batteries have high energy density (150-300 Wh/L), very reduced daily self discharge, a high rated capacity (up to 244.8 MWh) and high pulse capability [26–28]. One of its main advantages is also the use of inexpensive and non-toxic materials. Despite having all these advantages, the high FOM cost (80$/kW/year) and the extra system require to maintain the operating conditions does not make this technology as competitive.

As for the ZEBRA batteries the specific energy is between 94-120 Wh/kg, an energy density around 150 Wh/L, specific power between 150 and 170 W/kg and high operating temperatures between 523 and 623 K [14, 29]. The main advantages of this technology are the good pulse power capability, it is maintnance free, it has very low self-discharge and a relatively high cycle life [6].

1.2.2 Flow Batteries

This technology consists on two electrolyte contained in two reservoirs from which they are made circulate within a circuit that leads to an electrochemical cell that contains both electrolytes and a ion selective membrane separating as illustrated in the figure 1.6. The system generates energy through a reduction-oxidation reaction of the electrolyte solutions. While charging one of the electrolytes is oxidated at the anode while the other is reduced at the cathode. In order to charge the inverse process occurs.

Flow batteries can be categorized as redox flow batteries or hybrid flow batteries. This classification depends on whether all electroactive components can be dissolved in the electrolyte. The main flow battery designs are Vanadium redox, polysulphide bromide and zinc bromide [4].

One of the main advantages of this technology is that the power of its system is independent from the storage capacity. The power of a system with such technology is determined by the size of the electrodes and the cell number in the stack. Whereas the storage capacity is determined by the concentration of electrolyte. The disadvantages of this technology are the low performance as a result of non-constant pressure drops and the reactant mass transfer limitation, relatively high manufacturing costs and relatively complex systems when compared to traditional batteries [31].

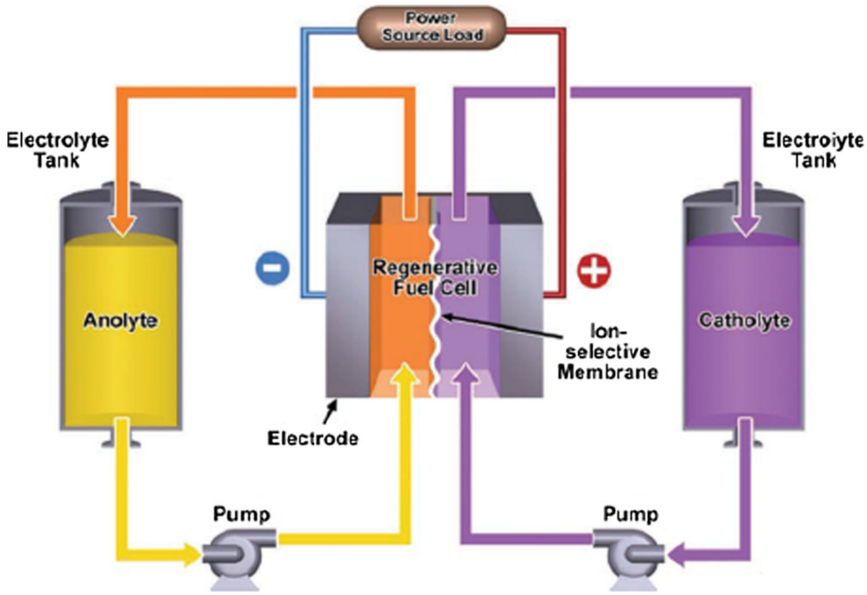

Figure 1.6: Flow Battery System [30]

The capital costs of this technology are between 600 and 1500 $/kW and 100 $/kW h [6, 32].

1.3 Electrical Energy Storage

1.3.1 Capacitor and Supercapacitor

A Capacitor has as a minimum of two electrical conductors that are separated by a thin layer of insulator. In this type of storage the energy is stored in the dieletric material in an electrostatic field [14, 33]. The maximum operating voltage of the capacitor depends of the breakdown characteristics of the dieletric material. The best use for this technology is to store small amounts of eletrical energy and conducting a varying voltage.

The power density is higher and the charging time shorter when comparing capacitors with conventional batteries [18]. However, the limited capcacity, low energy density and high self-discharging losses limit its applications [14, 33].

A Supercapacitor has two conductor electrodes, an electrolyte and a porous membrane separatinng as it is illustrated in the figured 1.7. The structure of the supercapacitor leads it to have characteristics from both traditional and electrochemical batteries. This technology stores energy in the form of static charge on the surfaces between the electrolyte and the two electrodes.

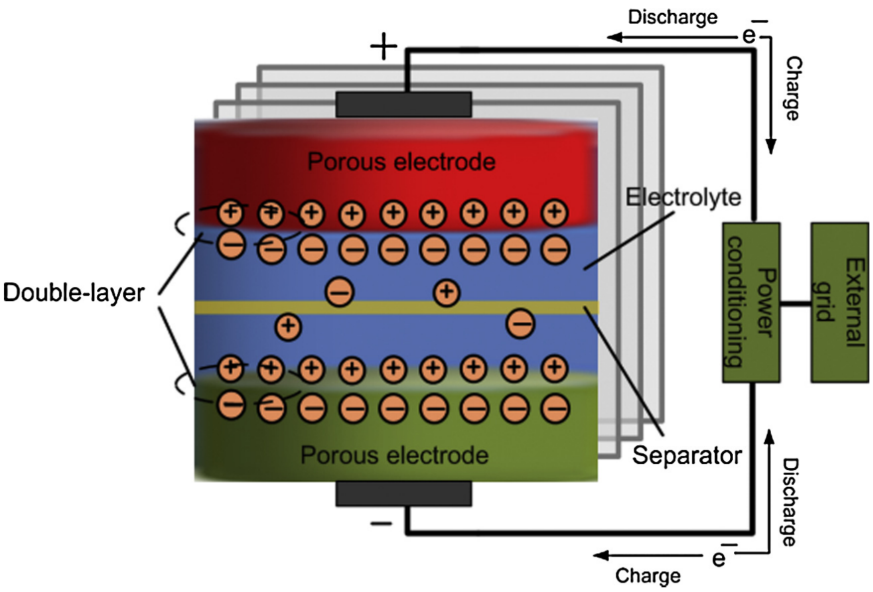

Figure 1.7: Supercapacitor System [6]

The most important characteristics of Supercapacitors are the long cycling times, over 1×10^5 cycles and high cycle efficiency, between 84% and 97% [14]. However, a high daily self-discharge rate and high capital costs are the limitations of this technology.

1.3.2 Superconducting Magnetic Energy Storage System (SMES)

SMES is typically formed by three main components: a refrigeration system, a vacuum subsystem, a superconducting coil unit and a power conditioning subsystem [26, 34, 35]. This system stores the electrical energy in the magnetic field generated by the Direct Current (DC) in the superconducting coil that has been cryogenically cooled to a temperature below its superconducting critical temperature. Generally, when current passes through a coil, the electrical energy will be dissipated as heat due to the resistance of the wire, however, if the coil is made of superconducting material, such as Vanadium or Mercury, under its super conducting state, zero resistance occurs and the electrical energy can be stored with very low losses [6, 14]. In the discharging mode the stored electrical energy is released back to alternated current (AC) through a power converter. The magnitude of the stored energy is determined by the self inductance of coil and the current flowing thorough it [36].

The SMES technology has a relatively high power density of around 2600 (kW/m^3), a fast response time (milisecond level), very quick full discharge time (less than one minute), high cycle efficiency between 90% and 97% and a long lifetime (around 30 years) [14, 27]. Another significant advantage is the capability of discharging near to the totality of the stored energy with little degradation after thousands cycles [6].

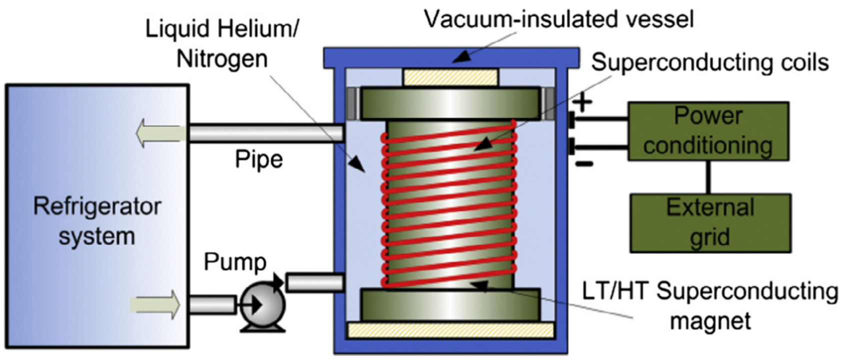

Figure 1.8: SMES System [6]

However, there are drawbacks as well, the capital cost, high daily self discharge (between 10% and 15%) and a negative environmental impact due to the strong magnetic field [14].

1.4 Chemical Energy Storage

1.4.1 Hydrogen Storage and Fuel Cell

Hydrogen energy storage systems are deeply associated to two separate processes for storing and producing electricity. On one hand the water electrolysis unit is a common way to produce hydrogen that can be stored at pressure in vessels [26]. On the other hand the fuel cell is used whenever is required the generation of electricity, as a result, this is a crucial technology for Hydrogen EES.

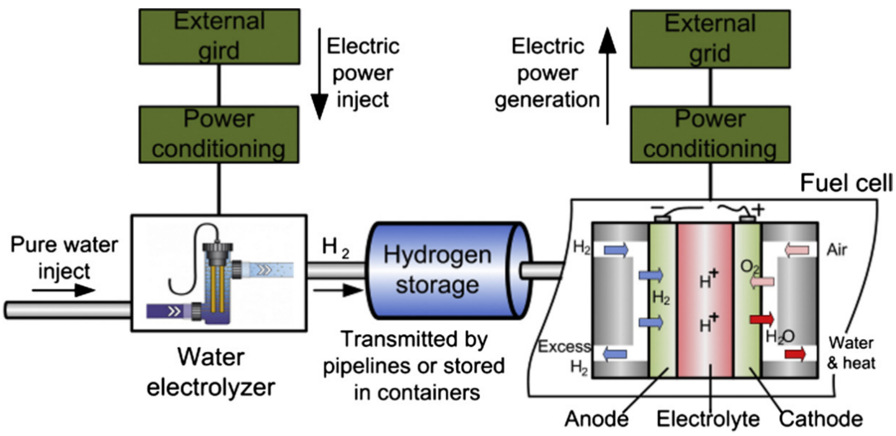

Figure 1.9: Hydrogen Storage System [6]

Fuel cells are able to convert chemical energy in hydrogen and oxygen into electricity [26]. The chemical reactions that reflect the process described are the following

$$2\,(H_2) + O_2 \longrightarrow 2\,(H_2O) + \text{energy [37]}$$

Heat and electrical energy are two of the products of the reaction as illustrated in figure 1.9. Fuel cells have 6 major groups: Alkaline Fuel Cell (AFC), Phosphoric Acid Fuel Cell (PAFC), Solid Oxide Fuel Cell (SOFC), Molten Carbonate Fuel Cell (MCFC), Proton Exchange Membrane Fuel Cell (PEMFC) and Direct Methanol Fuel Cell (DMFC) [37].

1.5 Thermal Energy Storage (TES)

TES encompasses a variety of technologies which store heat energy through different processes in insulated repositories. Ususally TES is described as a storage medium in a tank, a packaged chiller or built-up refrigeration system, piping, pump(s) and controls. Depending in the operating temperature TES can be classified in low temperature TES (aquiferous and cryogenenic energy storage) and high-temperatures TES (including latent heat TES, sensible heat TES and concrete thermal storage) [14].

The TES system can store large amounts of energy without major hazards and with a minimum self daily discharge loss (between 0.5% and 1%). However, the cycle efficiency is relatively low (between 30% and 60%) [14].

An example of a TES system is represented below in figure 1.10.

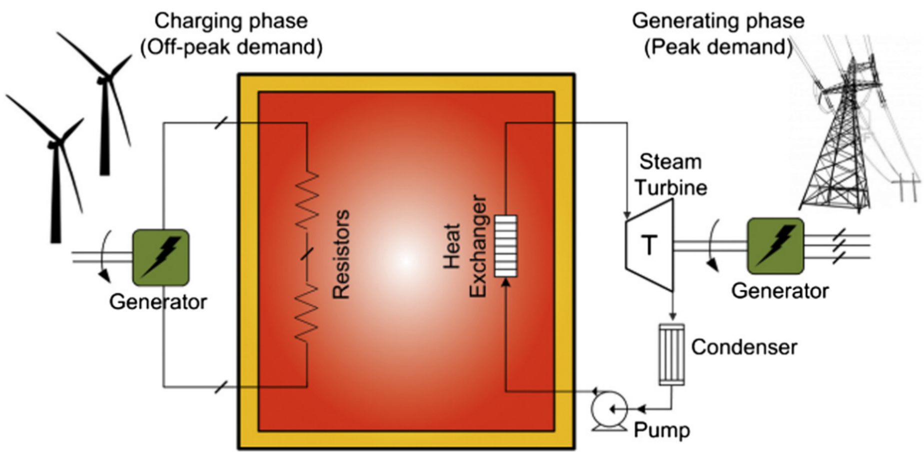

Figure 1.10: Sensible Heat Storage System [6]

Chapter 2

Caracterization of Cyprus

Cyprus is an island highly dependent on hydrocarbon energy resources and as the island does not have those resources its electricity production relies mostly on importations. The primary fuel used in electricity generation is heavy fuel oil and gas-oil. As a result, the electricity prices in Cyprus are among the highest in Europe [38].

2.1 Current Power Generation System

The Cypriot generation system is predominantly dominated by fossil fuel power generation technologies. An overview of the current system as well as new power power plants being commissioned within the next few years can be seen in figure 2.1.

Currently the Electricity Authority of Cyprus (EAC) owns and operates three power station as described in table 2.1. Vasilikos, the biggest power station in terms of installed capacity totalling 868 MW, Dhekelia the second biggest power station with 460 MW of total installed capacity and Moni power station being the smallest with a total installed capacity of 150 MW. The three thermal power stations have in total an installed capacity of 1,448 MW [40].

The electricity generation mix is predominantly dominated by thermal power generator as it has been already mentioned. However, an overview of the different electricity generation sources used in the island can be seen in tables 2.2 and 2.3. Table 2.2 allows a visualization of electricity generation from non-renewable sources by technology. Whereas table 2.3

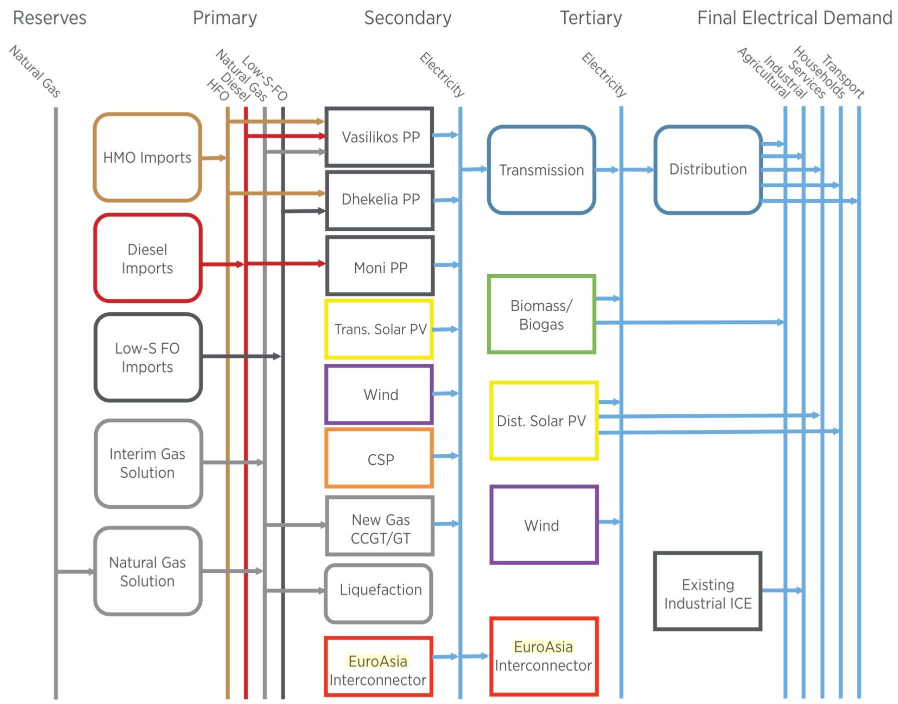

Figure 2.1: Cyprus Power Generation System [39]

Vasilikos Power Station	
3x130MW ST Units	390 MW
1x38MW OCGT Units	38 MW
2x220MW CCGT Units	440 MW
Vasilikos power station total installed capacity	**868 MW**
Dhekelia Power Station	
6x60MW ST Units	360 MW
2x50MW IC Units	100 MW
Dhekelia power station total installed capacity	**460 MW**
Moni Power Station	
4x37.5MW OCGT Units	150 MW
Moni power station total installed capacity	**150 MW**
Power stations total installed capacity	**1478 MW**

Table 2.1: Power Station Capacity in Cyprus [40]

Cyprus Generation Tecnologies	Thermal Power Generators (TPG)				
	ST	ICE	OCGT	CCGT	**Total TPG**
Power Capacity (MW)	750	100	188	440	**1478**

Table 2.2: Thermal Power Generation [40]

Cyprus Generation Tecnologies	Renewable Energy Sources (RES)				**Total**
	Wind	Solar PV	Biomass	**Total RES**	
Power Capacity (MW)	157.7	505317	12.4	**375.217**	**1853.217**

Table 2.3: RES Generation [40]

2.2 Renewable Energy Generation Potential

2.2.1 Solar Energy Generation

The climate of Cyprus is Mediterranean, cycling between hot, dry summers from June to September to cool and rainy winters from November to March, and brief spring and fall seasons in between. There are substantial differences, both daily and seasonally, in temperatures of coastal and inland areas.

The geographical location of Cyprus leads to an abundance of solar radiation which makes solar PV one of the most attractive renewable energy resource in the island. As represented in Figure 2.2 the potential for PV installation is very high. In the figure it is illustrated the average daily/yearly totals of electricity production from a 1 kW-peak grid- connected solar PV power plant for a period of 25 years (1994-2018).

Solar Energy options studied for Cyprus are Solar Thermal, Flat PV and Concentrated Solar Power (CSP). For the different technologies different parameters have different relevance. In the case of Flat PV the one of the most important parameters is the Global Horizontal Irradiation (GHI), which can be seen in Figure 2.3. However, for the CSP the most important parameter is the Direct Normal Irradiation (DNI), which can be seen in Figure 2.4.

In figure 2.3 it is possible to verify that there is a significant potential for Flat PV in all South coast of Cyprus with an intense GHI average irradiation between Paphos and Larnaca of around 2000 (kWh/m^2). Another relevant region due to its high irradiation is the area of Morphou with values around 1935 (kWh/m^2).

In figure 2.4 it is possible to verify that there is a significant potential for CSP in the South coast of Cyprus with an intense DNI average irradiation mainly around Limassol of approximately 2200 (kWh/m^2). Another relevant region due to its high irradiation is the area of Morphou with values of 2200 (kWh/m^2).

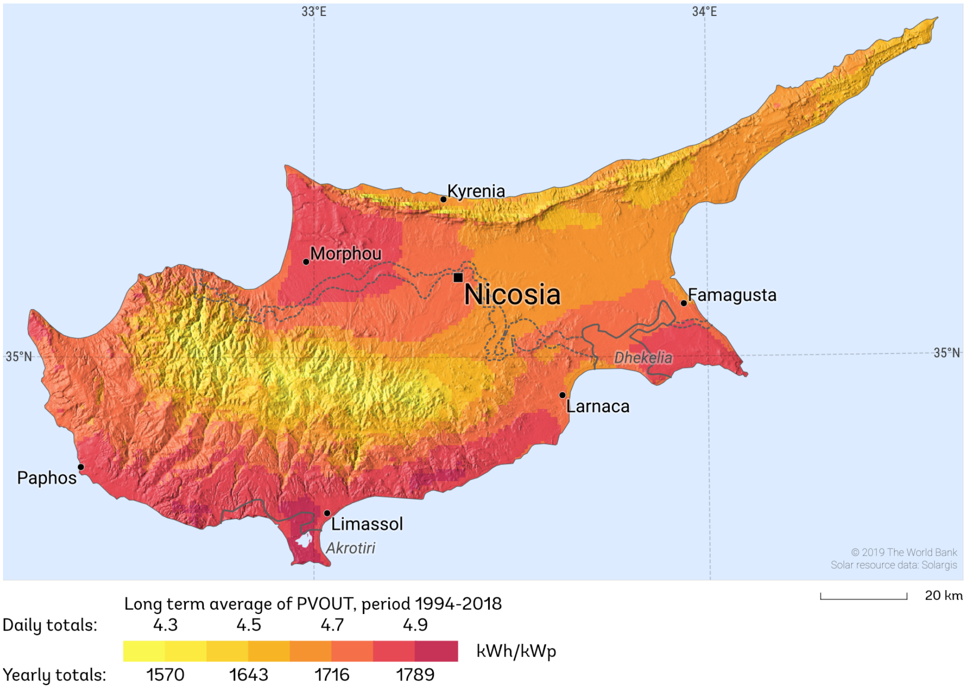

Figure 2.2: PV Potential in Cyprus [41]

2.2.2 Wind Energy Generation

Another very valuable natural resource of the island is the wind. Winds are generally light to moderate and variable in direction. Figure 2.5 shows the average annual wind speed profile of Cyprus. Average wind speed of 3- 4 (m/s) is dominant across the island. The blue region around Larnaca at the south-east part of the island represents an annual average wind speed of 4-5 (m/s). The area with the highest wind speeds is indicated by the yellow colour at the south-west of the island, around Limassol area, with wind speeds of 5-6 (m/s) [42].

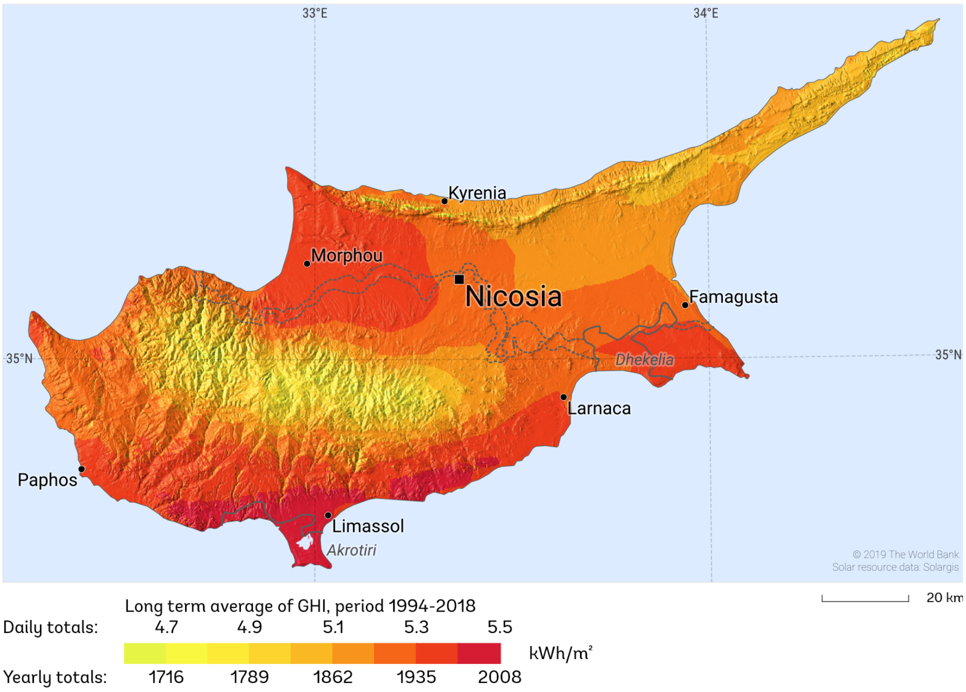

Figure 2.3: GHI Map of Cyprus [41]

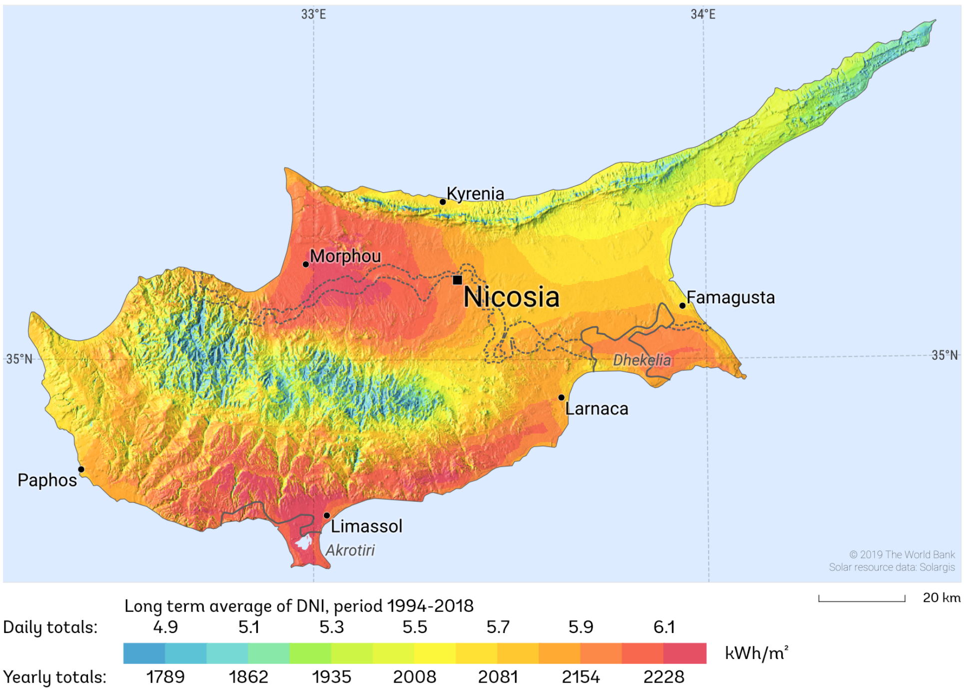

Figure 2.4: DNI Map of Cyprus [41]

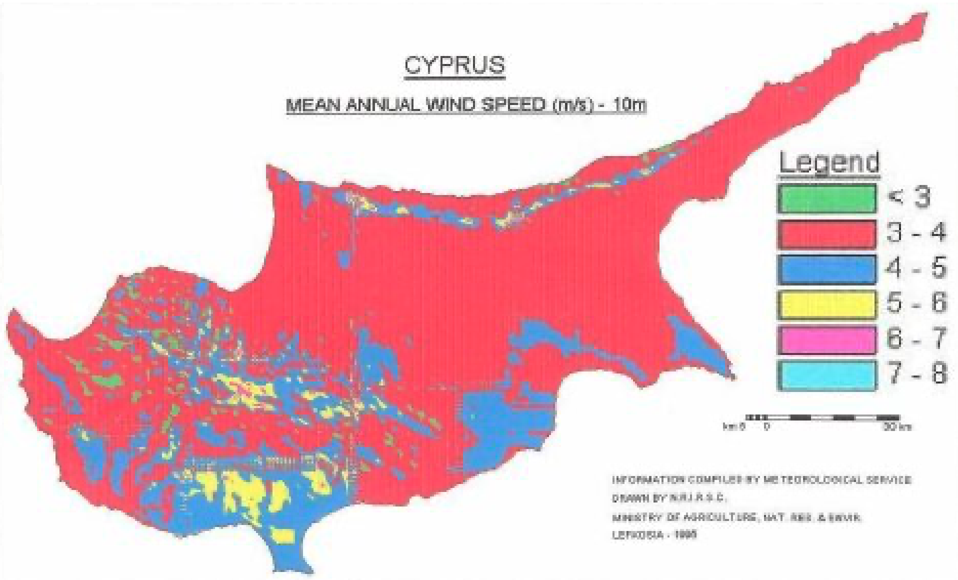

Figure 2.5: Wind Map of Cyprus [42]

2.3 The Evolution of Power Generation

At the beginning of the year 2020 the green deal was signed by all the European Union (EU) country members. This agreement is a commitment to be climate neutral by 2050 [43]. As a result, all EU members will have to contribute to a significant reduction in Carbon emissions. As the Electricity Generation accounts for 40% of the overall CO_2 emissions around the world [44] the EU wants to play a key role changing this paradigm. Consequently, and according to the national limitations of each one the countries, each country will contribute to the overall carbon neutrality by 2050.

In line with the Green Deal the Cyprus Integrated National Energy and Climate Plan 2021-2030 is an analysis of the current situation of the energy sector and how the government intends to develop this sector throughout the coming decade. This document presents the evolution of the energy generation mix in Cyprus for the upcoming years as it can be seen in Figure 2.6. Through the figure it is possible to assess the phase out of HFO fuel generators as well as a significant increase in Gas generated energy. However, the share of renewables in the energy production mix is only expected to reach approximately 20% by 2030, which is a considerably low value taking into consideration the targets at which the EU as a whole is aiming for [45].

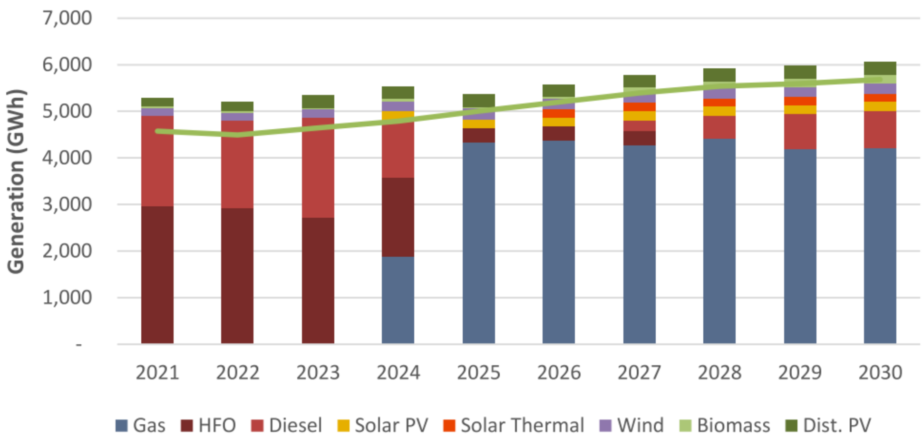

Figure 2.6: Generation Mix Evolution [45]

A major on going project, the EuroAsia connector, that is planned to be finished by 2023 [3] will also affect significantly the energy mix and the possibilities of either storage and production. This is due to the 1000 (MW) capacity of the cable, which provides a notorious flexibility to an island that was so far isolated and completely dependent on hydro-carbonate fuels importation.

2.4 The Evolution of Electricity Demand

The demand of any system is always important, however when considering isolated systems there is an even more significant importance. If not carefully planned there can be moments of shortage as the island relies only on its own resources. As a result a prediction of the evolution of the demand as shown in Figure 2.7 is crucial. It is essential from the point of view of the current situation, and the short term evolution that the system needs to have in order to adapt to the current demand, but also to dimension a reliable system that can sustain the evolution of the demand.

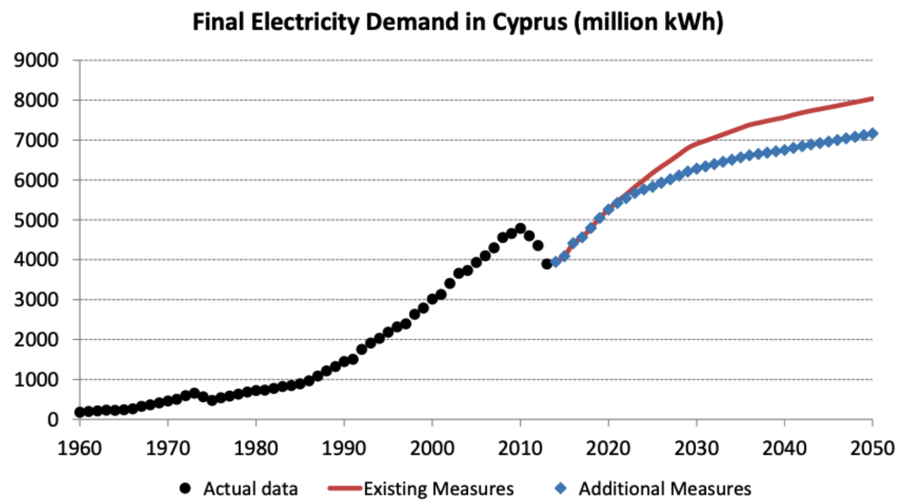

Figure 2.7: Electricity Demand Evolution [45]

In figure 2.7 it is also possible to observe that by 2030 the expected demand is between 6500 (kWh) and 7000 (kWh).

Chapter 3

Methodology

Cyprus is one of the EU countries that is fully committed with both the Green Deal and the Paris Agreement. As a result, the decarbonization is a priority in this country agenda, and has developed its own plan to reach the ambitious goals for the decade. This plan started to be drafted in 2016 and it has been updated ever since, annually. This plan is the basis for the study performed in this document as it sets the paradigm for the upcoming years of the Cypriot energy mix. This study aims to identify what are the best energy storage scenarios for the Republic of Cyprus taking into consideration the current situation, the scenarios in the plan for the decade studied by the Cypriot Government and the evolution and cost of the technologies available [6]. In this section an overview of the approach and the methods that were used in each step are shown. The whole process followed is illustrated step by step in Figure 3.1.

Once the aim of the work was clearly defined, it was extremely important to have the right steps to follow in order to obtain the desired objective. As a result, a research on articles regarding similar topics took place which led to an article on ”Integral approach to energy planning and electric grid assessment in a T renewable energy technology integration for a 50/50 target applied to a small island” [46]. This article provided the right guidance to conduct the study in Cyprus, an island currently isolated from the grid as the one presented in the article.

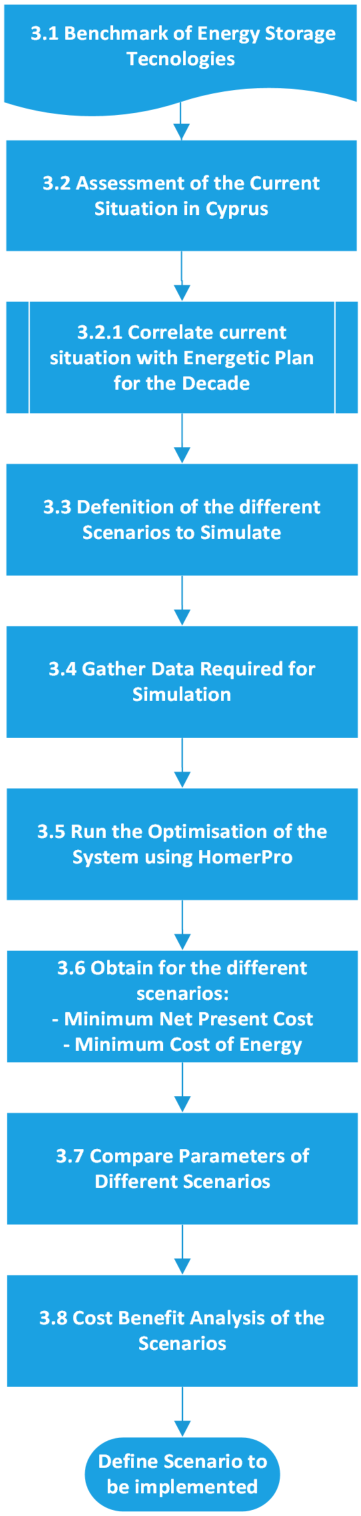

Figure 3.1: Methodology to analyze the implementation of a Renewable Energy Storage System in Cyprus for 2040

3.1 Benchmark of Energy Storage Technologies

In order to be able to provide asses which flexibility solutions could be installed in 2040, it was necessary to know which technologies could be suitable or not. This benchmark was based on scientific articles from which it was possible to have an overview of the different ES technologies as well as its progression throughout the past and coming years. One of the most relevant articles for the purpose was the ′Overview of current development in electrical energy storage technologies and the application potential in power system operation′. This article provides an excellent overview of all the technologies according to the different categories: Mechanical Energy Storage, Electrical Energy Storage, Electrochemical Energy Storage, Chemical Energy Storage and Thermal Energy Storage.

3.2 Assessment of the Power System in Cyprus

After the literature review on the storage technologies state of the art, the following step was to obtain a holistic picture of Cyprus' electrical power generation system. To do so a thesis on "The Integration of Renewable Energy, Natural Gas Thermal Power Generators, Energy Storage, and Interconnection in Cyprus" [47] was used. This Master Thesis that has recently been done provided a great

3.3 Scenarios Definition

Once the assessment of the energy generation mix planned for 2040 was performed it was possible to set up the different possible scenarios. Firstly, it is important to define the general constraints of the system, which will be denominated Base Scenario. These are going to be used as the general conditions for each one of the specific scenarios. In table 3.5

3.3.1 Base Scenario

In the Base Scenario it is necessary to define all the variables that will be common to the different specific scenarios. Those variables are the load of the system, the base energy generation mix among other specific constraints.

Load of the System

The load for the considered case study of Cyprus is a projection for 2040 based on the demand of 2017. The load from 2017 was obtained through the European Transparency Platform of the Transmission System Operators (ENTSOE) [?] and it is an hourly characterization of the load throughout the 365 days of 2017.

Based on the figure 2.7 it was possible to forecast the energy demand for 2040.

ETSEIB

Table 3.1 illustrates the process to calculate the estimated average daily load for 2040.

Year	Average Loads (kW)
Average from 2017	513756.74
2020	570776.26
increment from2020	9.99%
2030	696347.03
increment from 2020	26%
2040	776255.71
increment from 2020	34%

Table 3.1: Average Daily Load Projection

-	2017
Energy (kWh)	4500000000
Capacity (kW)	513698.6301
Error	0.011310%

Table 3.2: Error Estimation of Average Daily Load

The estimation based on Figure 2.7 can be considered accurate based on the calculation shown in Table 3.2. The Energy in the second row is calculated based on the average daily load obtained from the database of ENTSOE and shown in the second row of Table 3.1 and compared to the value obtained from Figure 2.7 once converted . These calculations are illustrated by the figures 3.2,3.3 and 3.4.

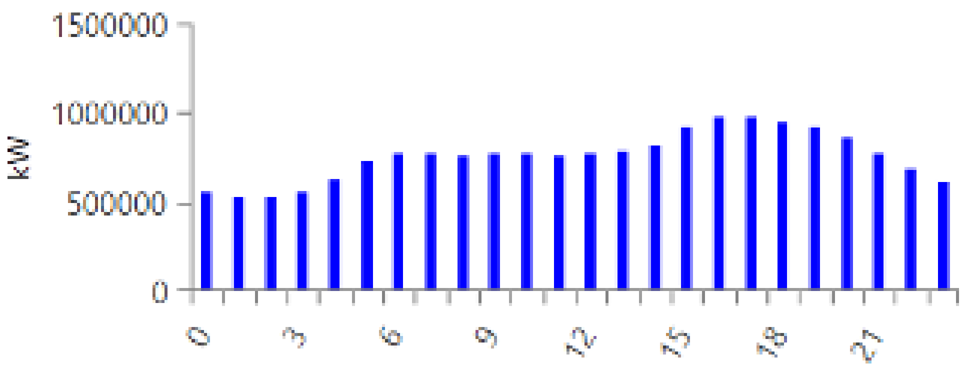

Figure 3.2: Projected Daily Load Profile of Cyprus in 2040

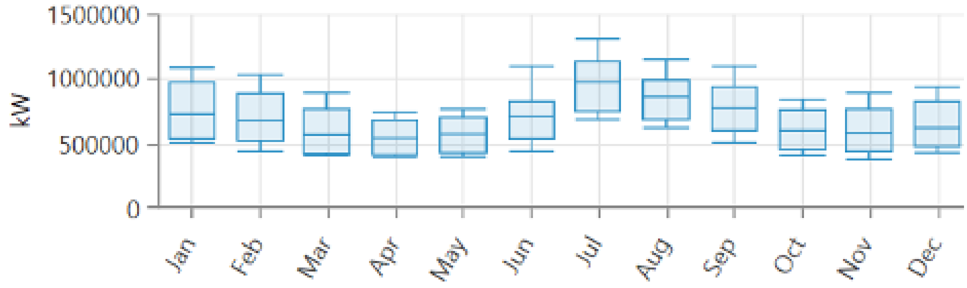

Figure 3.3: Projected Seasonal Load Profile of Cyprus in 2040

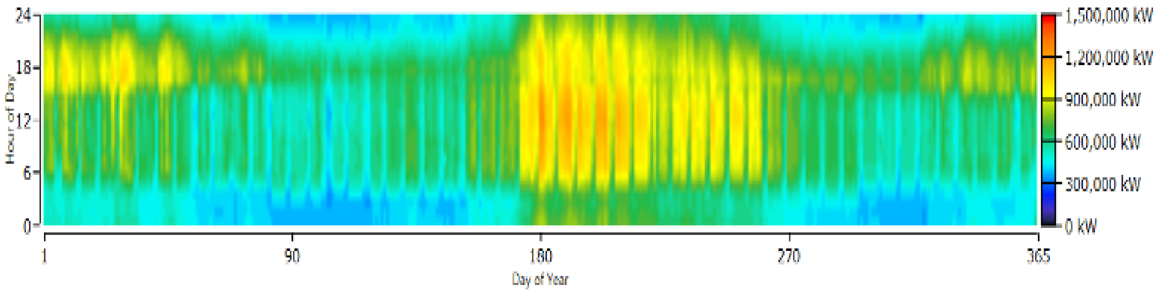

Figure 3.4: Projected Yearly Load Profile of Cyprus in 2040

Electricity Generation Mix

The electricity generation mix of Cyprus is predominated by the GHG technologies as mentioned in the chapter of Caracterization of Cyprus. However, the plan to change this paradigm is being implemented and the generation mix presented in the table 3.3 is the one predicted for 2040. Despite mentioning light fuel oil as one of the energy generation sources several other documents that also characterize the evolution of the generation energy mix throughout the next decades eliminate it by 2040 as the Cyprus Draft Integrated National Energy and Climate Plan for the period 2021-2030 - Republic of Cyprus [45]. As a result, in this analysis, the capacity associated to this technology was replaced by biogas generation as it appears in the envisaged scenario of the national energy mix up to 2055, where fuel oil electricity generation is not mentioned [3].

For simulation purposes, as well as optimization of the different energy generation sources, all planned infrastructure for 2040 in the document of Cyprus Integrated National Energy and Climate Plan 2021-2030 [3] was set as the minimum capacity for each of the technologies listed in table 3.3. Through this method is possible to avoid situations such as results that completely mismatch a possible reality by not making use of existing energy generation resources that are predicted to exist at the time.

Two parameters extremely important as an input to perform the analysis of the system are the Capital Cost and the Operation and Maintenance Costs. As a result, all these parameters are present in Table 3.4 for the Base Scenario.

Type	Capacity 2040 (MW)	Fraction
Light Fuel oil CHP	26	1.17%
Solar PV	1631	73.20%
Wind	198	8.89%
Biogas	64	2.87%
PHES	130	5.83%
Li-ion	179	8.03%
Total	**2228**	**100.00%**

Table 3.3: Energy Generation Mix 2040 [3]

Generation Tecnology	Model	Capital Cost (€/kWh)	O&M (€/kW/year)
Wind Generation	Vestas 85 2MW	1000	35
Solar PV	Peimar SG300MBF	650	7.5
BioGas Turbine	Generic Turbine	3400	35

Table 3.4: Capital and OM Cost of the Base Scenario

Specific Constraints

The envisioned scenario of the Cypriot government for 2040 estimates a penetration of RES of approximately 65% [3]. Consequently, this parameter was defined as a minimum value of penetration of renewables across the different specific scenarios.

Furthermore, a minimum of 20% of battery was established as the limit of discharge of the storage units in all the cases. To notice that in a similar case, Cozumel island, a minimum of 30 minutes was established [46]. In the case of Cyprus, the interconnection of the EuroAsia cable provides more confidence in the generation system resulting in a lower minimum value, justified still by the will of the country to have backup solutions in case of any failure in the system [3].

The Direct Normal Irradiance (DNI) for the case study is based on the location of Nicosia due to its good location for both wind and solar generation as it can be seen in the chapter of Caracterization of Cyprus [41]. This data base provided the average DNI per hour of the day on the different months of the year.

The Global Horizontal Irradiation (GHI), the temperature and the wind profiles in the figures are based on NASA Prediction of Worlwide Energy Resource Database which is based on a 22 year period of data collection. Figures 3.93.7 and 3.8 reflect the values in that same database.

Direct normal irradiation [Wh/m^2]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5						2						
5 - 6				12	181	281	175	68	2			
6 - 7			111	259	443	548	499	426	325	125	27	
7 - 8	125	238	382	438	567	679	648	605	589	476	328	141
8 - 9	380	420	500	530	656	765	753	720	705	605	505	395
9 - 10	466	500	563	588	703	816	823	795	771	672	587	479
10 - 11	500	535	589	600	706	830	852	827	789	680	610	510
11 - 12	495	524	588	583	680	813	840	812	761	641	597	495
12 - 13	460	492	546	553	638	775	818	778	706	575	565	480
13 - 14	437	463	512	537	616	756	798	749	662	532	519	449
14 - 15	397	433	502	512	583	730	762	709	616	484	460	395
15 - 16	315	373	431	453	539	687	704	649	559	407	324	243
16 - 17	62	201	326	369	478	618	621	557	426	156	35	9
17 - 18		3	53	149	312	492	487	328	71			
18 - 19					20	103	101	16				
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	3635	4180	5104	5583	7123	8895	8880	8038	6984	5352	4559	3596

Figure 3.5: Average DNI per hour of the day of each month in Nicosia 2019

Figure 3.6: Average DNI per hour of the day of each month in Nicosia 2019 [41]

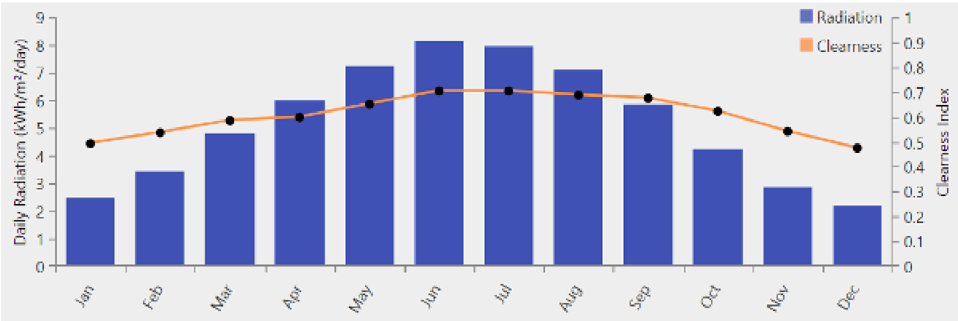

Figure 3.7: Average GHI profile per month in Nicosia

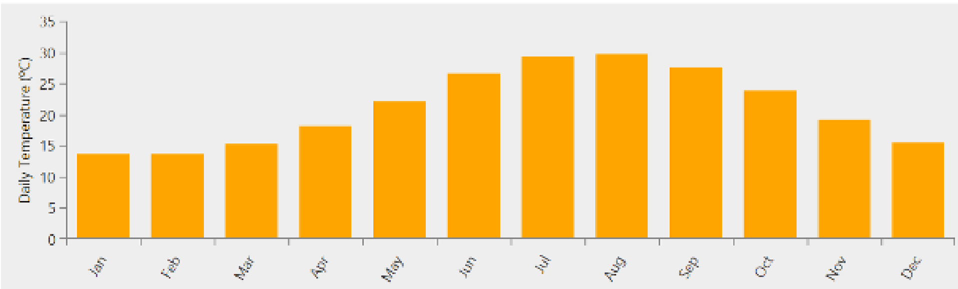

Figure 3.8: Average Temperature Profile per month in Nicosia

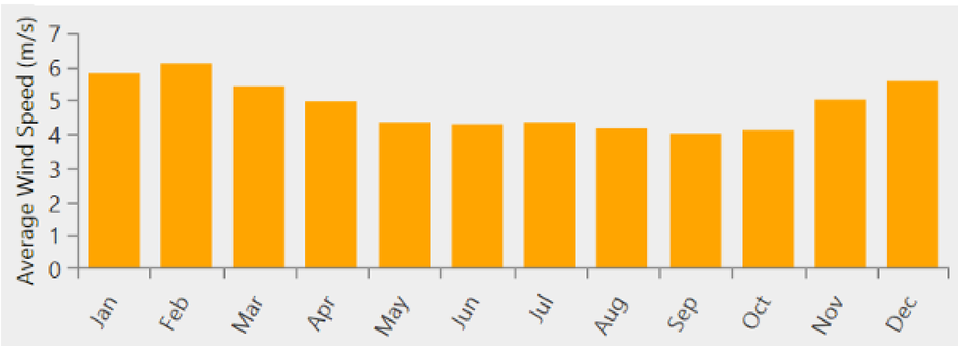

Figure 3.9: Average Wind Profile per month in Nicosia

3.3.2 Specific Scenarios

After defining the base energy scenario of Cyprus 2040, the three different variations previously mentioned, are now presented into more detail. For this, different storage technologies previously presented are paired up for each specific scenario, in order to evaluate which ones are more suitable for the Cyprus case. Table 3.5 shows the technologies assigned to each of the scenarios. In the three cases, HOMER uses in the most optimized results one of the two available technologies as only type of technology, therefore leaving no room for hybrid storage systems.

Apart from that, for each specific scenario, three different price possibilities have been considered for each technology, taking into account the uncertainty around the future prices of these storage systems. Therefore, for every scenario, there will be an ”optimistic” scenario called ’Rno’, an ”expected” scenario called ’Rne’ and a ”pessimistic” scenario called ’Rnp’, always being the ’n’ the number of the specific scenario.

Specific Scenario	RES involved
P1	PHES + Li-ion
P2	Flywheel + Lead Acid
P3	VRFB + Supercapacitor

Table 3.5: Specific Scenarios

Specific Scenario 1 (P1)

This scenario is a combination of the base scenario with PHES and Li-ion as energy storage technologies to match the needs of the system. The most relevant set up information for these technologies is shown in Table 3.6.In this case, as it was described for the generators, the planned infrastructure for 2040 was taken into consideration and set as a minimum capacity for optimization.

Scenario P1				
ES technology	Model	CC (€/kWh)	O&M (€/kW/year)	Uncertainty(%)
PHES	Generic 245kWh PH	100	3	8
Li-ion Batteries	Generic 1MWh Li-Ion	340	8.5	3

Table 3.6: Storage detail of scenario P1

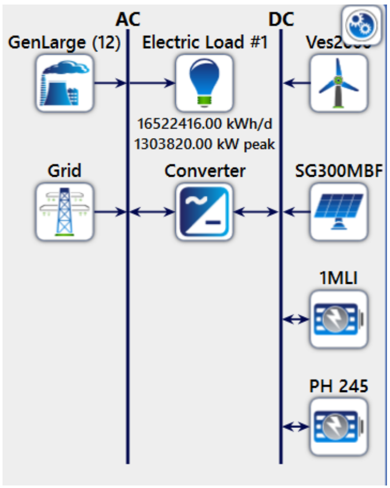

Figure 3.10: System diagram of P1

Specific Scenario 2 (P2)

This second scenario is also a variation of the base scenario, but now with flywheel and lead acid batteries as energy storage technologies to compensate the big renewable share of the system. The most important definition information for these technologies is shown in Table 3.7

ES technology	Model	CC (€/kWh)	O&M (€/kW/year)	Uncertainty (%)
Flywheel	ABB PowerStore	250	0.125	6
Lead Acid Batteries	Generic 1kWh	127.5	10	6

Table 3.7: Storage detail of scenario P2

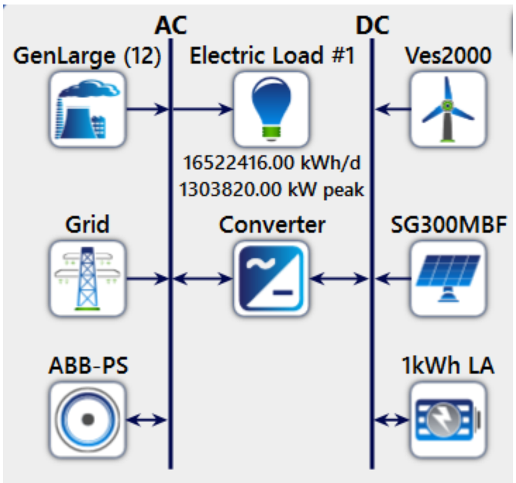

Figure 3.11: System diagram of P2

Specific Scenario 3 (P3)

This third set up is the last a variation of the base scenario, using as energy storage technologies NAS and VRFB batteries this time instead. The most relevant set up information for these technologies is shown in Table 3.8

ES technology	Model	CC (€/kWh)	O&M (€/kW/year)	Uncertainty (%)
NAS	BASF Battery	255	70	6
VRFB	UET Reflex V7	127.5	-	9

Table 3.8: Storage detail of scenario P3

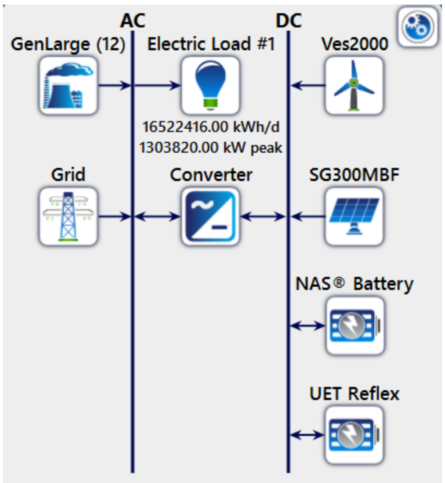

Figure 3.12: System diagram of P3

3.4 Homer Pro Simulations

Once all the specific cases are defined, the following stage is to run the different scenarios through Homer Pro in order to optimize the resources that are given as an input to the program.

Homer Pro makes use of two algorithms in order to optimize the system with different strategies.

On one hand, the load following strategy dispatched strategy whereby whenever a generator operates, it produces only enough power to meet the primary load- Lower-priority objectives such as charging the storage bank or serving the deferrable load are left to the renewable power sources. The generator may still ramp up and sell power to the grid if its economically advantageous [48].

On the other hand, the cycle charging strategy is a dispatch strategy whereby whenever a generator needs to operate to serve the primary load, it operates at full output power. Surplus electrical production goes towards the lower-priority such as, in order of decreasing priority: serving the deferrable load, charging the storage bank, and serving the electrolyzer [48].

Some pertinent constraints for the simulation were left as advised by the program. Those variables are 10% of load in current time step, a percentage of renewable output of 80% in the case of solar and 50% in the case of wind.

One of the significant limitations of the software is the fact that the program can only optimize four components of the system in its free version. As a result, for the scope of the study the components to be optimized were in all of the cases the EG from Solar and Wind as well two components of storage at the time. This is the reason behind the presentation of three different specific scenarios and not one simulation in which there is a variation of the CC of the ES technologies as idealized at the beginning of the development of the presented work.

3.5 Cost Benefit Analysis

Perform an analysis based on the parameters that result as an outcome of the simulation, levelized cost of energy (LCOE(, net present cost (NPC) and renewable share generation. This analysis takes into consideration both the results of the simulation as well as the objectives of the Cypriot government and the goal of the European Union.

The main objectives assessed on the side of the Cypriot government are the will to rely less on importation of energy source depending less as a result on foreing resources. The will to be less dependent on prices oscillations as it currently occurs due to the variations in the prices of crude and Natural Gas over time. Moreover, the high emissions of CO_2 are also one of the main concerns.

From the European Union perspective it is crucial that Cyprus decreases its GHG emissions. As a member of the EU the country represent a key element in the joint effort to comply with both the Green Deal and the Paris Climate Agreement [43].

Chapter 4

Results

This section presents the results obtained at the end of the different set up simulations using HOMER Pro. The various graphs and tables are used as support to present the main calculations and results obtained in the simulation. As presented in the Methodology, Homer followed the optimization algorithm of Load Following to obtain the best results in each one of the optimized results in each one of the scenarios [48]. It should be highlighted Homer Pro chooses to use only one of the technologies in each one of the presented scenarios. As a result, the sensitive variation of the CC is regarding the technology being utilized.

4.1 P1

The first specific scenario presents pumped hydro energy storage (PHES) and Li-ion batteries as the possible ES technologies to be considered. In the top optimized scenarios Li-ion batteries are presented as the only storage technology to be used in the system. Furthermore, the sensitive analysis performed on the CC of the ES technology did not affect the resulting capacity of each one of the components of the system as presented in table 4.1. The values presented in this simulation represent roughly 37 times more ES capacity from Li-ion batteries, than the one represented in 3.3. It should be taken into consideration though that in P1 there is no presence of PHES in opposition to what is shown in table 3.3. However, when comparing the overall capacity of the system predicted in Table 3.3 with P1, the last one shows 21 times more ES capacity.

In P1 it is possible to observe a significant presence of solar generation when compared to wind generation similarly to the prediction of the Cypriot authorities in Table 3.3. Other crucial data resultant from the simulation are the 275% more solar GC and 203% more wind GC when compared to the data in table 3.3. These results are a direct comparison between the values in Table 4.1 and the ones shown in Table 3.3. However, it should be taken into consideration the 65% of renewable generation by 2040 and the limit of 15% the use of the capacity of the EuroAsia interconnector.

Case	Relative CC	EG Source Capacity (kW)			ES Capacity (kWh)
		Solar	Wind	Biomass	Li-ion
R1o	0.97	4485799.8	802000	90000	6647
R1p	1.03	4485799.8	802000	90000	6647
R1e	1	4485799.8	802000	90000	6647

Table 4.1: Installed Capacity of P1

In figure 4.1 the clear highest net present cost was the scenario where the cost of the technology is the pessimistic, being of around 6.9B€. In opposition the one that has a better NPC is the optimistic scenario as it could be predicted. The difference of price between the highest NPC and the lowest value derives exclusively from the sensitive analysis being performed on the CC of the Li-ion batteries.

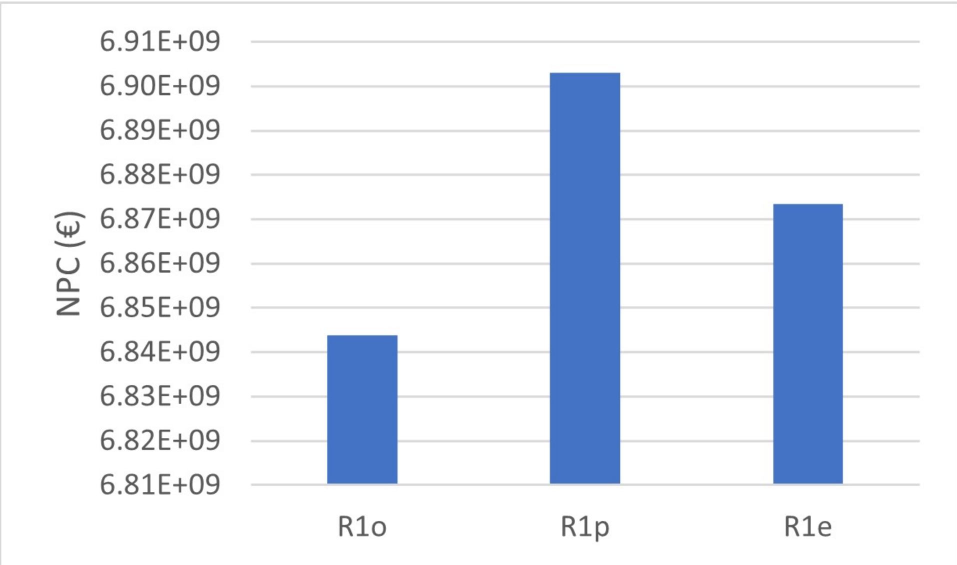

Figure 4.1: Net Present Cost of P1

As for the LCOE represented in figure 4.2 the clear highest LCOE was the scenario where the cost of the technology is the pessimistic, being of around 0.0686€. In opposition the one that has a lowest LCOE is the optimistic scenario as it could be predicted. The difference of price between the highest LCOE and the lowest value derives exclusively from the sensitive analysis being performed on the CC of the Li-ion batteries.

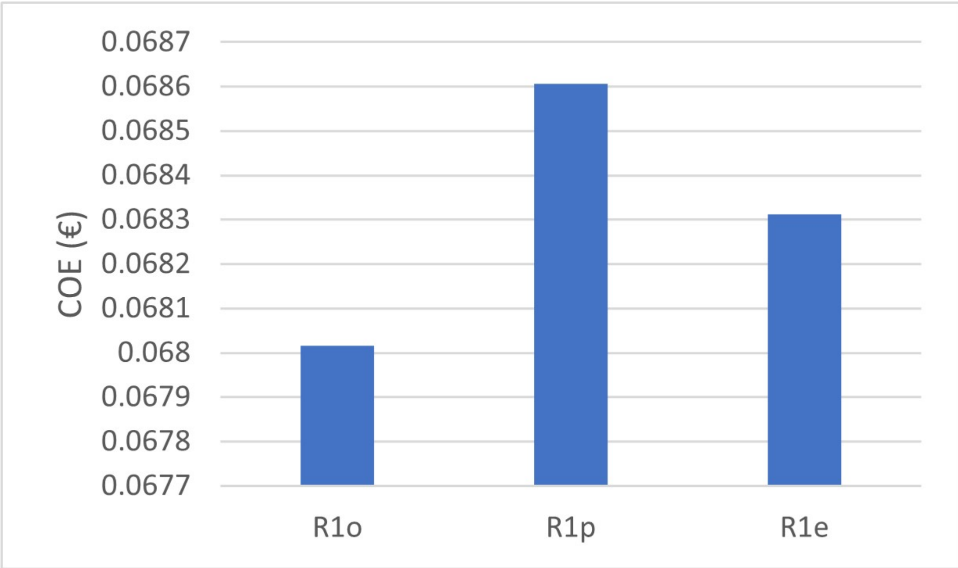

Figure 4.2: Levelized Cost of Energy of P1

4.2 P2

The second specific scenario presents Flywheel and Lead Acid batteries as the possible ES technologies to be considered. In the top optimized scenarios Flywheel is presented as the only storage technology to be used in the system. Furthermore, the sensitive analysis performed on the CC of the ES technology did not affect the resulting capacity of each one of the components of the system as presented in table 4.2. The values presented in this simulation represent roughly 21 times more ES capacity from Flywheel, when compared to the combined ES Capacity in 3.3. This results is a direct comparison between the values in table 4.2 and the ones shown in table 3.3

In P2 it is possible to observe a significant presence of solar generation when compared to wind generation, however more significant than the one mentioned in prediction of the Cypriot authorities mentioned in table 3.3. Other crucial data resultant from the simulation are the 379% more solar GC and 134% more wind GC when compared to the data in table 3.3. These results are a direct comparison between the values in Table 4.2 and the ones shown in Table 3.3. However, it should be taken into consideration the 65% of renewable generation by 2040 and the limit of 15% the use of the capacity of the EuroAsia interconnector.

Case	Relative CC	EG Source Capacity (kWh)			ES Capacity (kWh)
		Solar	Wind	Biomass	Flywheel
R1o	0.94	6182171.511	532000	90000	1830
R1p	1.06	6182171.511	532000	90000	1830
R1e	1	6182171.511	532000	90000	1830

Table 4.2: Installed Capacity of P2

In Figure 4.3 the clear highest net present cost was similar for all the specific scenarios being of around 6.9B€. This is due to the low impact of the CC of the Flywheel on the overall cost of the system. In figure 4.4 the clear highest net present cost was

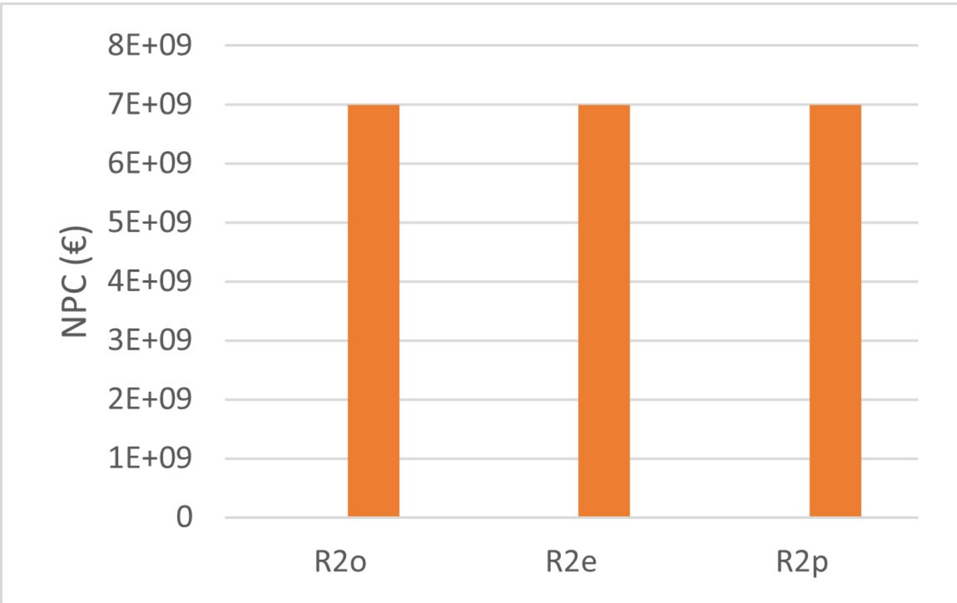

Figure 4.3: Net Present Cost of P2

similar for all the specific scenarios being of around 0.0601208€. This is again due to the low impact of the CC of the Flywheel on the overall cost of the system.

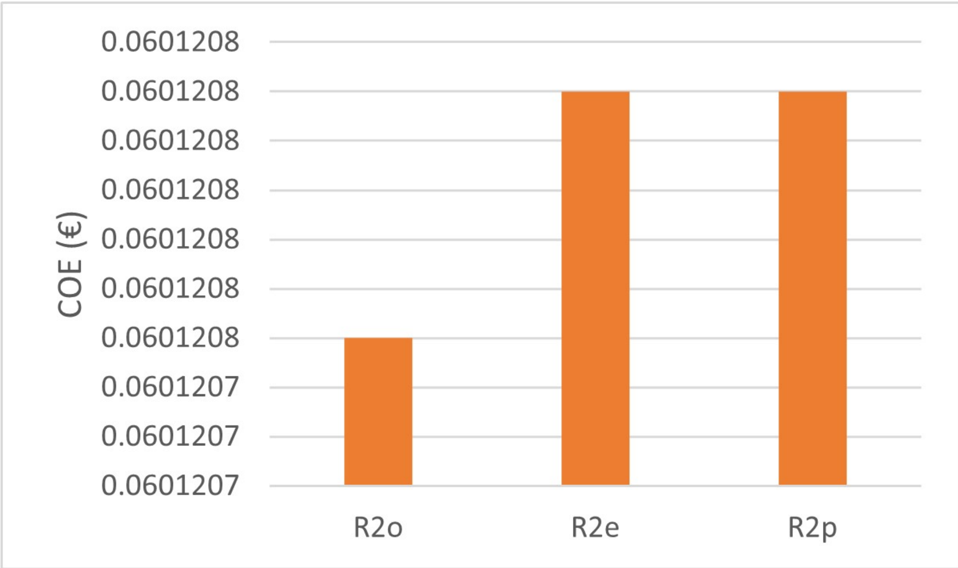

Figure 4.4: Levelized Cost of Energy of P2

4.3 P3

The third specific scenario presents NaS and VRFB as the possible ES technologies to be considered. In the top optimized scenarios NaS is presented as the only storage technology to be used in the system. Furthermore, the sensitive analysis performed on the CC of the ES technology in P3 was the only one from the three specific scenarios that changed the whole configuration of the system as presented in table 4.3.

The values presented in this simulation reveal an estimated ES capacity roughly between 3.5 and 7 times more, when compared to the overall ES Capacity in 3.3 as it can be seen in table 4.4. These results are a direct comparison between the values in Table 4.3 and the ones shown in Table 3.3

In P3 it is possible to observe a significant presence of solar generation when compared to wind generation, however more significant than the one mentioned in prediction of the Cypriot authorities mentioned in table 3.3. Other crucial data resultant from the simulation are the added solar GC and wind GC when compared to the data in Table 3.3 as hown in Table 4.4. These results are a direct comparison between the values in Table 4.3 and the ones shown in Table 3.3. However, it should be taken into consideration the 65% of renewable generation by 2040 and the limit of 15% the use of the capacity of the EuroAsia interconnector.

Case	Relative CC	Generation Source Capacity (kW)			Storage Capacity (kW)
		Solar	Wind	Biomass	NaS
R1o	0.94	3594965.768	768000	90000	3342
R1p	1.06	4770190.994	572000	90000	3074
R1e	1	3888851.937	770000	90000	4908

Table 4.3: Installed Capacity of P3

Case	Relative CC	Solar	Wind	NaS
R1o	0.94	220%	388%	3894%
R1p	1.06	292%	289%	3581%
R1e	1	238%	389%	5718%

Table 4.4: Comparison between P3 and Cypriot Plan [3]

In figure 4.5 the clear highest net present cost was the scenario where the cost of the technology is the pessimistic, being of around 6.9B€. In opposition the one that has a better NPC is the optimistic scenario as it could be predicted. The difference of price between the highest NPC and the lowest value derives not only from the sensitive analysis being performed on the CC of the Li-ion batteries, but also from the different configurations adopted.

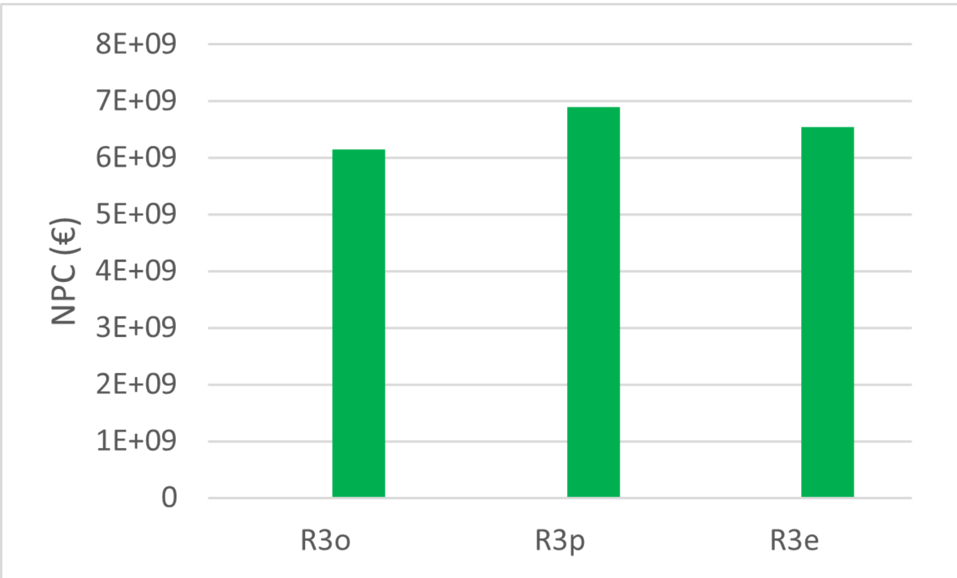

Figure 4.5: Net Present Cost of P3

In figure 4.6 the clear highest LCOE was the scenario where the cost of the technology is the pessimistic, being of around 0.07€. In opposition the one that has a better LCOE is the optimistic scenario. The difference of price between the highest LCOE and the lowest value derives not only from the sensitive analysis being performed on the CC of the NaS, but also from the different configurations adopted. It is interesting to oberve that despite having a significant lower storage capacity it still has the highest LCOE R3p.

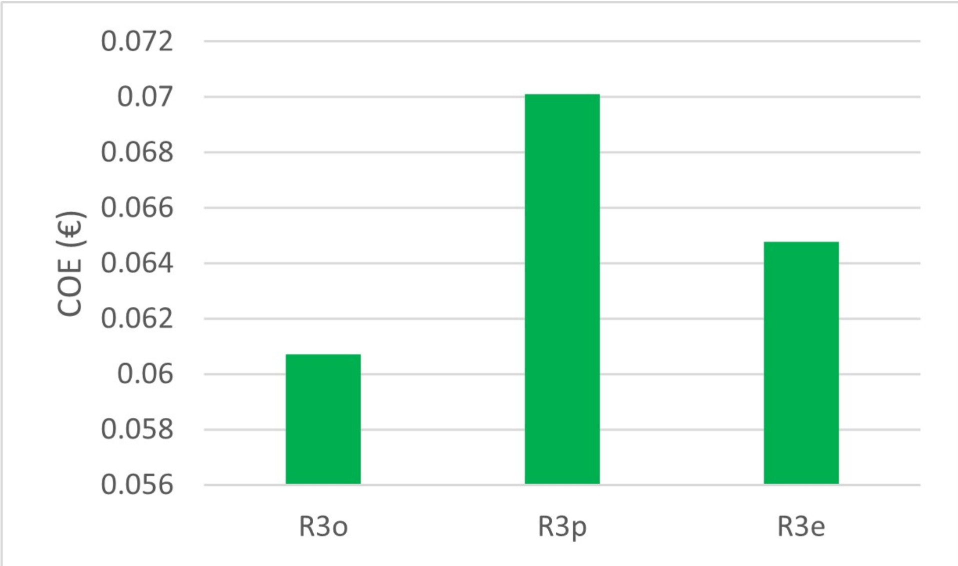

Figure 4.6: Levelized Cost of Energy of P3

4.4 Comparison of Scenarios by Uncertainty

To be able to also see the different results obtained from crossing the previously mentioned pairs of technology, in this section the results are compiled and represented together.

4.4.1 Optimistic Capital Cost

When considering the three optimistic scenarios together, without discriminating by technology, it can be noticed that the lowest net present cost corresponds to the NAS batteries scenario, with under 6.2B€compared to the other two technologies, which have a figure of around 7B€as illustrated in figure 4.7.

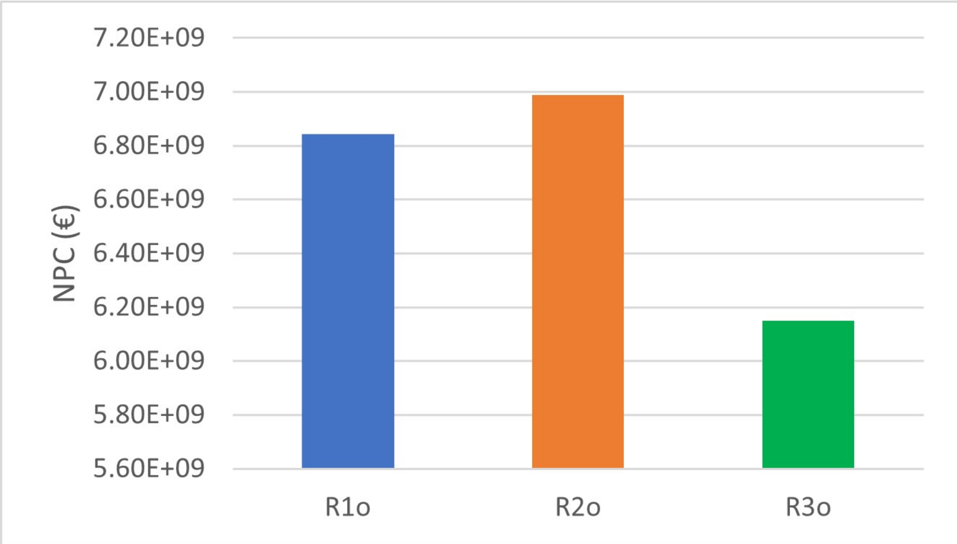

Figure 4.7: Net Present Cost of optimistic scenarios

Moreover, when analyzing the LCOE of these three scenarios together in the optimistic scenario, the lowest cost of energy is linked to the flywheel technology, being the NAS batteries considerably close as illustrated in figure 4.8.

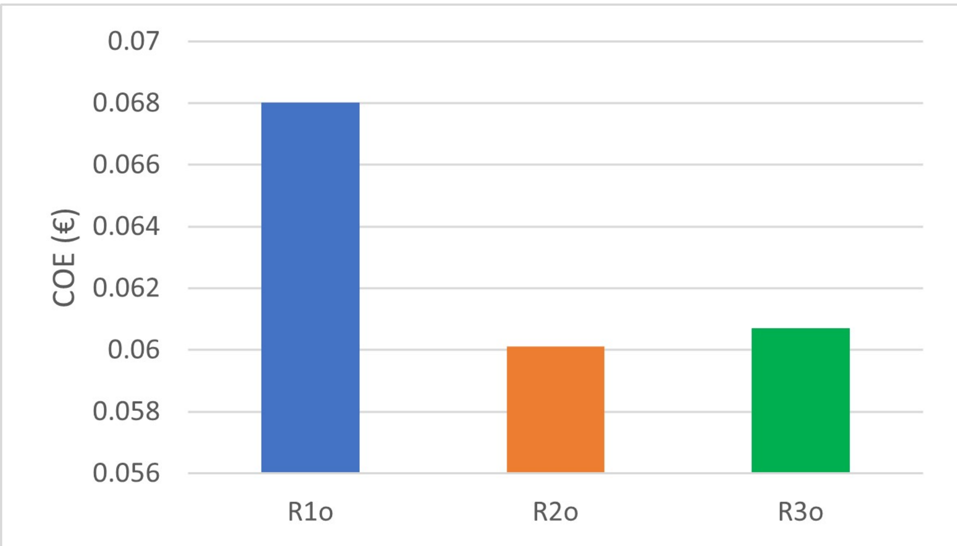

Figure 4.8: Levelized Cost of Energy of optimistic scenarios

4.4.2 Expected Capital Cost

Similarly to the previous case, when studying the expected cases together, the highest net present cost is associated with the specific scenario P2, or what is the same, the flywheel technology as illustrated by figure 4.9. Apart from that, the highest LCOE in this case is also seen in the first scenario, R1e, corresponding to the Li-ion batteries as illustrated in figure 4.10.

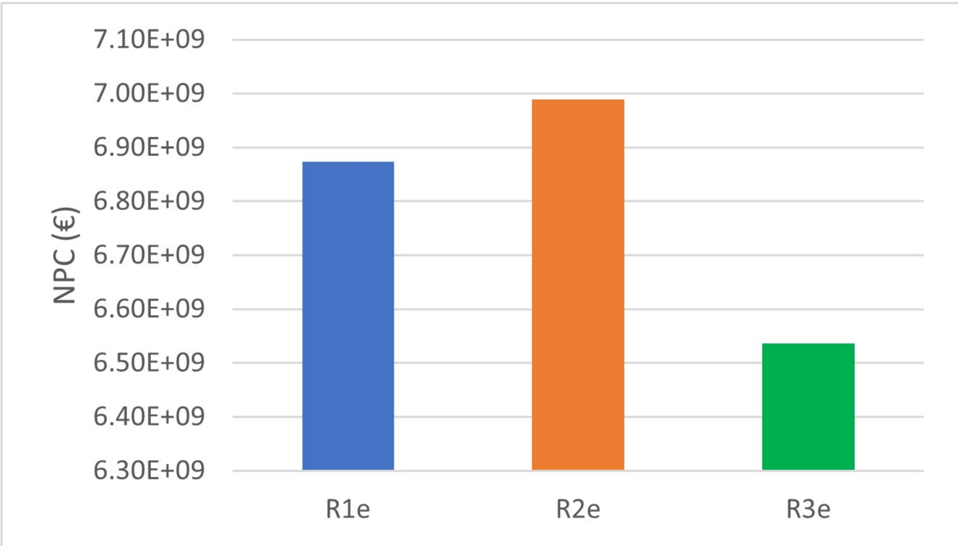

Figure 4.9: Net Present Cost of expected scenarios

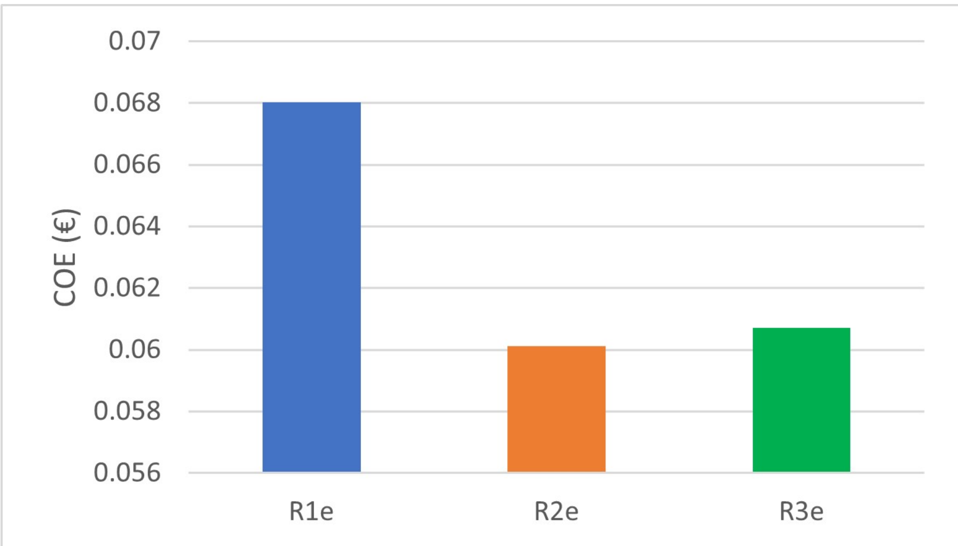

Figure 4.10: Levelized Cost of Energy of expected scenarios

4.4.3 Pessimistic Capital Cost

Lastly, for the pessimistic scenarios, the highest future prices for all the technologies, the same pattern can be noticed. The highest net present cost, is related to the second specific scenario.

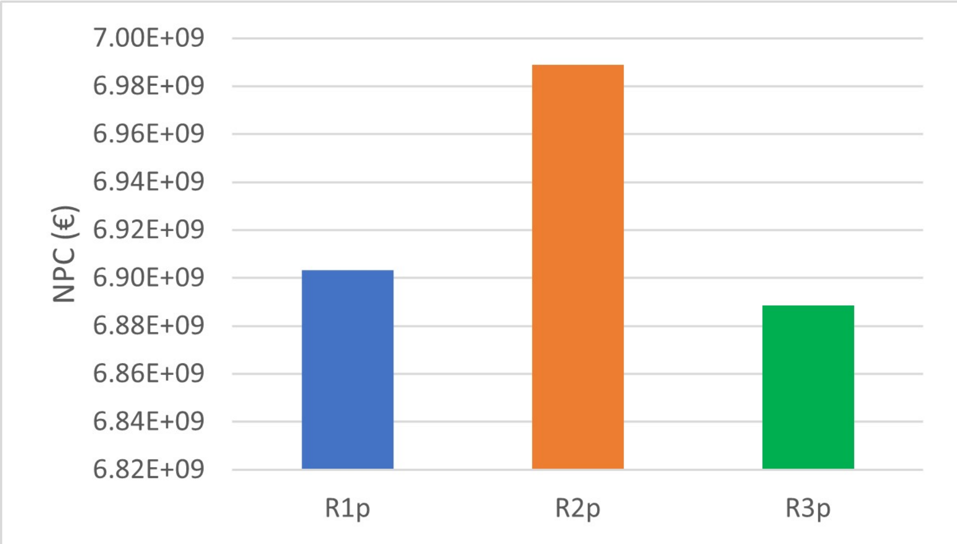

Figure 4.11: Net Present Cost of pessimistic scenarios

However, in contrast with the NPC it also accounts for the lowest cost of energy when compared to the other two as illustrated in figure 4.11. This is due to the low OM cost associated with Flywheel when compared with the other ES technologiesas as illustrated in figure 4.12.

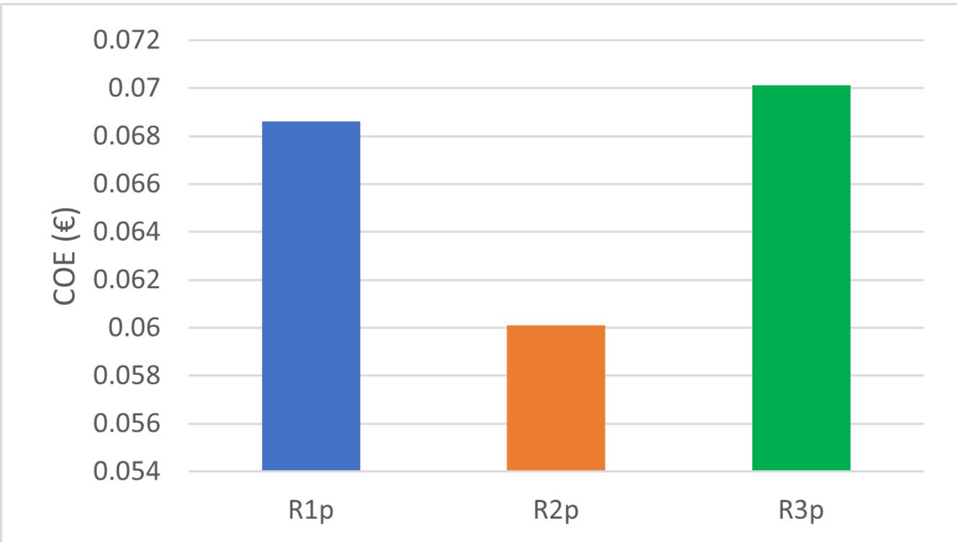

Figure 4.12: Levelized Cost of Energy of pessimistic scenarios

4.4.4 Overview

In the following figures all the scenarios are presented together, to be able to compare the two figures, NPC and LCOE, together. The lowest net present cost overall is the scenario R3o, with the NAS batteries as illustrated in figure 4.14, while the lowest cost of energy corresponds always to the scenarios related to the flywheel technology as illustrated in figure 4.13.

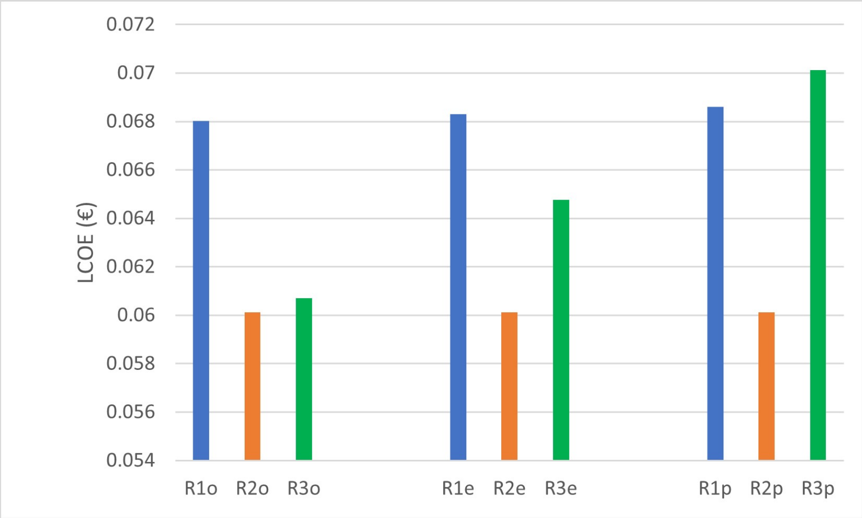

Figure 4.13: Levelized Cost of Energy of all scenarios

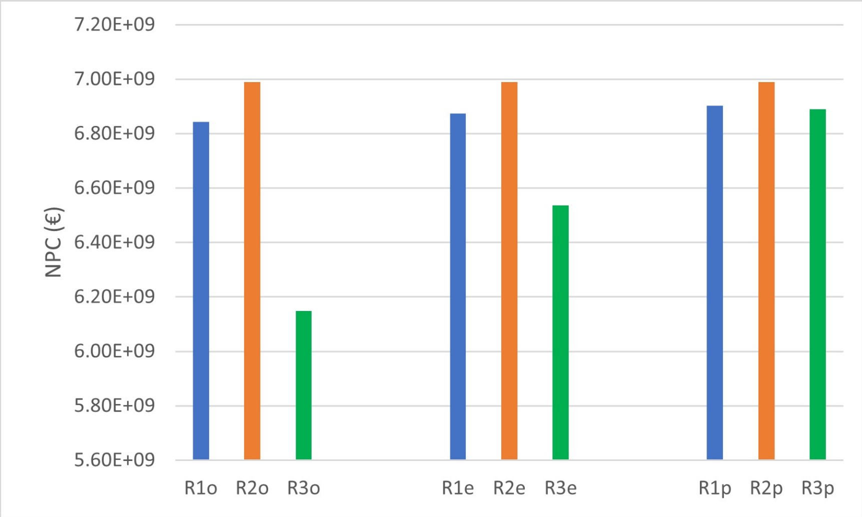

Figure 4.14: Net Present Cost of all scenarios

Apart from the pure economical results, it is interesting also to check the difference of renewable penetration between the three scenarios. As it can be seen in Figure 4.15 the first scenario is the one with a highest share of renewables, accounting for 91.9%.

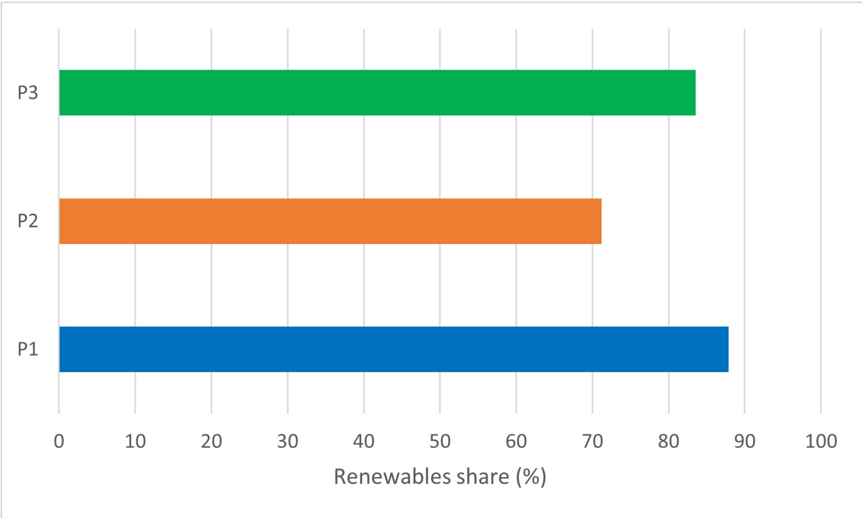

Figure 4.15: Renewable share of P1,P2 and P3

This overview of the different possibilities for Cyprus in 2040 given the technologies in analysis leads to an analysis of the different possibilities available for the future of the island.

Chapter 5

Conclusions

Through this study is possible to observe the impact that the development of ES technology has on the CC and consequently on dimensioning systems such as the one being analyzed in the medium term. The sensitive analysis performed for each one of the specific cases allowed to observe the impact that the small variations in the CC have in the ES technology to be implemented in the system. This can be confirmed by the table 4.3 where there were variations of the whole configuration of the system only due to the variation of one parameter, the CC.

From the financial point of view it is possible to observe that regarding the LCOE the Flywheel is the tecnology that performs the best in all CC variation scenarios, only being rivaled by NaS in an optimistic evolution of its CC. However, regarding the NPC it is possible to observe that NaS technology is the one that performs the best in the different scenarios only being rivaled by Li-ion in a pessimistic CC scenario.

From an environmental point of view, the system with the most penetration of renewables and consequently the lowest GHG emissions is the Li-ion with 87.9% being only rivaled by NaS which averaged 83.6% among the different configurations of the system. However it should be highlighted that in the configuration of the expected CC scenario the renewable penetration reaches 88.26%.

All these configurations lead to a significant reduction of the GHG emissions as demanded by the EU and the Cypriot Government. Moreover, this foreseeable future relies significantly less on importation of primary energy sources being those importations only associated with the Natural Gas used in the turbine that makes use of co-firing to use biomass.

All in all, it was possible to observe that the P3 configuration with NaS being the technology applied is the recommended system. NaS has the LCOE that performs as second best in the different cases with the exception of the pessimistic CC scenario where it performs the worst. As for its NPC it performs the best in all the different scenarios. Regarding the GHG emissions, it performs the second best only behind Li-ion by a small percentage and in an optimist CC scenario it can even perform best. As for the strategic objectives of the Cypriot Government it provides the independence required in [3] Further data on all the analysis can be seen in Appendix C.

5.1 Future work

The results presented in this analysis were limited to the optimization capabilities of the free version of the program Homer Pro. As a result it is suggested to use a different program in order to simulate all the different technologies in the same simulation. This might affect the outcome as there might be a hybrid ES possibility that has not been considered in this analysis.

Furthermore, the simulation of the considered system with non-existent technologies in the program Homer Pro might lead to a better suggested configuration of the system.

Lastly, the nonexistence data on the EuroAsia cable might have influenced the results of the simulation. As a result, it is suggested to use the real data after 2023 when this component will be introduce to the Cypriot grid [3].

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Annex A

Environmental Impact

The environmental impact of the elaboration of this project can be considered extremely reduced due to the fact that it did not require any form of mobility. Consequently, did not contribute to GHG emissions of means of transport. Regarding the purchase of the goods listed in the budget they were acquired through a Carbon Neutral store as well.

Annex B

Budget

Following, the economic costs associated to this master thesis are presented. The project was started 1st of April 2020 and finished 29th October 2020. Therefore, the overall development of the study has represented a total of X hours for the student, and assuming that an hour of a junior engineer is worth 10€, the total cost of the thesis is 10 €.

Project cost	
Start date	1st April 2020
End Date	29th October 2020
Total worked days	160
Worked hours/day	4
Total worked hours	640
Engineer cost/hour (€)	10
Total cost (€)	**6400**

Apart from this, less representative costs have been calculated, such as the office material, like notebooks, a whiteboard and markers. Together with that, the electricity consumption during the working hours has also been computed. For that, a computer and two led lights have been considered to consume 60 Wh per worked hour, at a price of 0,139406 €/kWh.

Other costs	
Office material (€)	50
Electricity (€)	5,35
Total cost (€)	**55,35**

Therefore, the total cost of the master thesis taking into account the 21% VAT, is 7811 €.

Total cost	
Project cost (€)	6400
Other costs (€)	55,35
VAT (21%)	1356
Total cost (€)	**7811**

Annex C

Simulation Reports

Microgrid Proposal

PREPARED FOR:

Li-ion/PHES_R1p, Li-ion_PHES_R1p
Unnamed Road, Lefkoşa 99040

PREPARED BY:

Your Name, Your Title
Your Company Name, Your Email
Your Phone Number

This proposal was generated using HOMER Pro, a dynamic software engine that runs complex simulations of your hybrid electrical system's energy data and system components to determine the least-cost solution and most effective risk-mitigation strategies. Originally developed at the US Department of Energy's National Renewable Energy Laboratory (NREL), HOMER software set the global standard for optimizing microgrid design. More than 200,000 HOMER Pro users worldwide have produced economic feasibility studies, system design, engineering insight, and energy cost savings.

Table of Contents

PREPARED BY:

Your Name,

Your Title, Your Company Name,

Your Email,

Your Phone Number

HOMER Pro

Project Summary

CURRENT SYSTEM

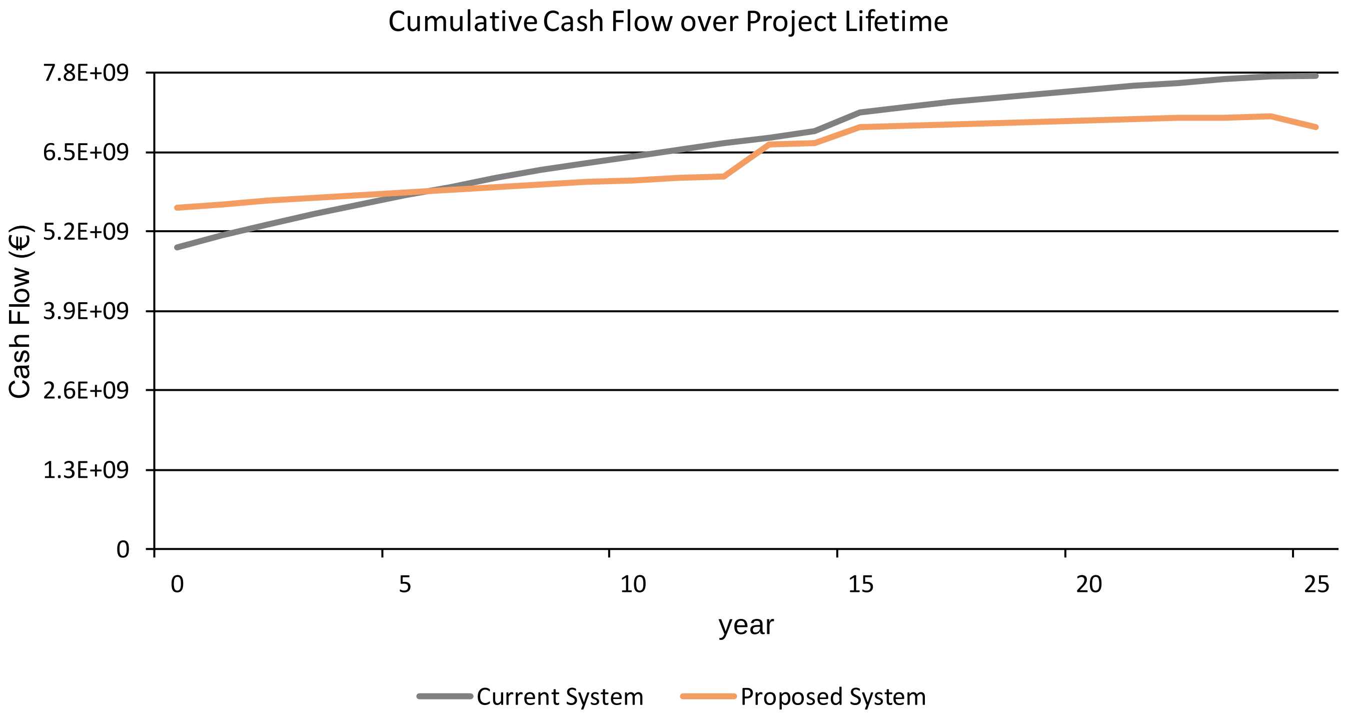
The electric needs of Unnamed Road, Lefkoşa 99040 are met with 90,000 kW of generator capacity, 7,665,212 kWh of battery capacity and 3,408,000 kW of wind generation capacity. Your operating costs for energy are currently €217M per year.

PROPOSED SYSTEM

We propose adding 4,485,800 kW of PV. This would reduce your operating costs to €102M/yr. Your investment has a payback of 4.62 years and an IRR of 18.7%.

Simple payback:	4.62 yr
Return on Investment:	16.0 %
Internal Rate of Return:	18.7 %

Net Present Value:	€843M
Capital Investment:	€650M
Annualized Savings:	€115M



ABOUT YOUR COMPANY NAME

Use this section to introduce your company name and explain what your business does, where you operate (or the markets you serve), and how long you've been doing it for. About Us page is the ideal place to accommodate several objectives:

- Communicate the story of your business and why you started it.
- Describe the customers or the cause that your business serves.
- Explain your business model or how your products are made

Customer Testimonials

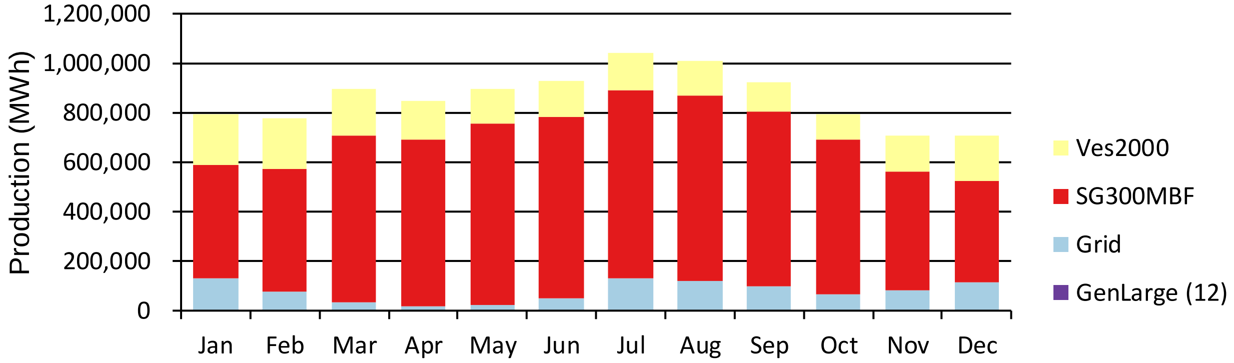
Use this space to provide statements made about your company by satisfied customers. Quotes and positive comments are valuable to prospective clients as they evaluate their options and decide whether your company's services provide the best solution to fit their needs. Testimonial statements demonstrate how others have benefited from your company's services, making them a powerful tool for establishing trust and encouraging potential clients to take action.

—John J. Client, CEO - Your Happy Client, Inc.

Consumption Summary

Electric Consumption

This microgrid requires 21316395 kWh/day and has a peak of 1818918 kW. In the proposed system, the following generation sources serve the electrical load.



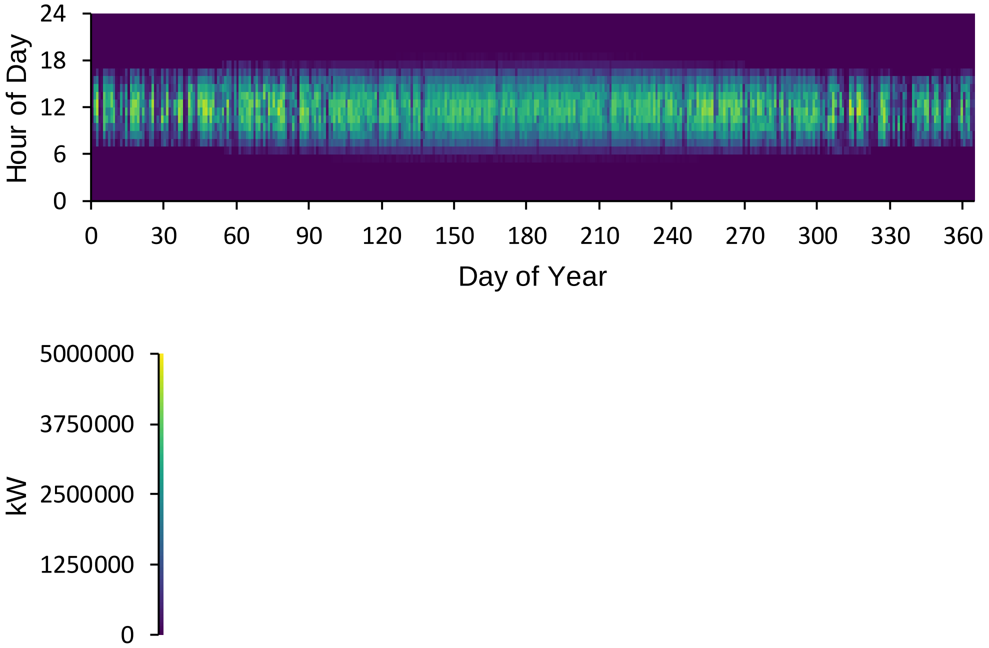
PREPARED BY:
Your Name,
Your Title, Your Company Name,
Your Email,
Your Phone Number

PV: Peimar SG300MBF

The Peimar Inc. PV system has a nominal capacity of 4,485,800 kW. The annual production is 7,501,490,176 kWh/yr.

Rated Capacity	4,485,800 kW
Capital Cost	€2.92B
Specific Yield	1,672 kWh/kW
PV Penetration	124 %

Total Production	7,501,490,176 kW
Maintenance Cost	15,251,719 €/yr
LCOE	0.0309 €/kWh

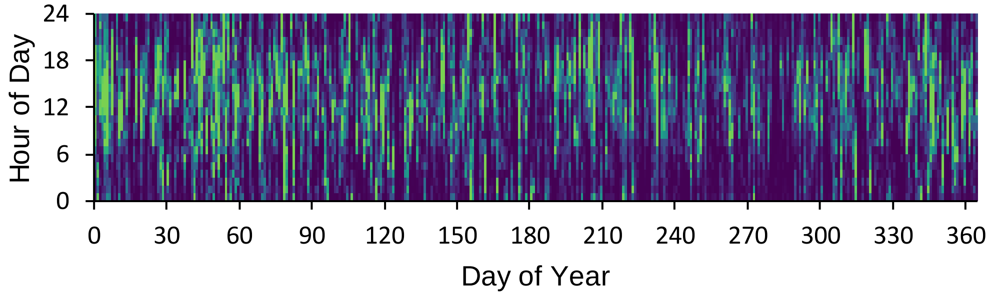


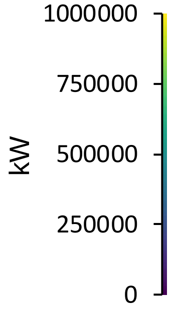
Wind Turbine: Vestas V90-2.0

Power output from the Vestas wind turbine system, rated at 802,000 kW, is 1,878,918,528 kWh/yr.

Quantity	401
Wind Turbine Total Production	1,878,918,528 kWh/yr
Capital Cost	€802M
Wind Turbine Lifetime	20.0 years

Rated Capacity	802,000 kW
Hours of Operation	7,837 hrs/yr
Maintenance Cost	23,618,900 €/yr


24
18
12
6
0
Hour of Day
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of Year


1000000
750000
500000
250000
0
kW

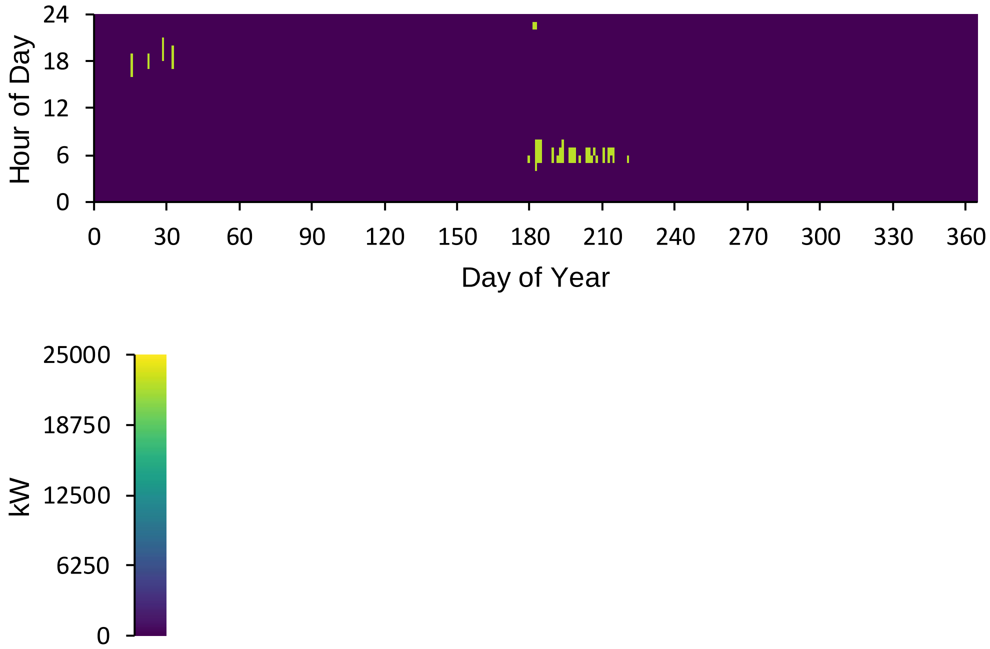
Engineering Details

Generator: biomass (Natural Gas)

Power output from the Generic generator system, rated at 90,000 kW using Natural Gas as fuel, is 1,215,000 kWh/yr.

Capacity	90,000 kW
Operational Life	278 yr
Capital Cost	€306M
Fuel Consumption	72,900 m³
Hours of Operation	54.0 hrs/yr
Fixed Generation Cost	21,291 €/hr

Generator Fuel	Natural Gas
Generator Fuel Price	0.300 €/m³
Maintenance Cost	20,520 €/yr
Electrical Production	1,215,000 kWh/yr
Marginal Generation Cost	0.0989 €/kWh



Storage: Generic 1MWh Li-Ion

The Generic storage system's nominal capacity is 6,647,002 kWh. The annual throughput is 1,654,909,056 kWh/yr.

Rated Capacity	6,647,002 kWh
Annual Throughput	1,654,909,056 kWh/yr
Maintenance Cost	24,718,532 €/yr
Autonomy	7.72 hr

Expected Life	12.0 yr
Capital Costs	€1.02B
Losses	174,155,088 kWh/yr

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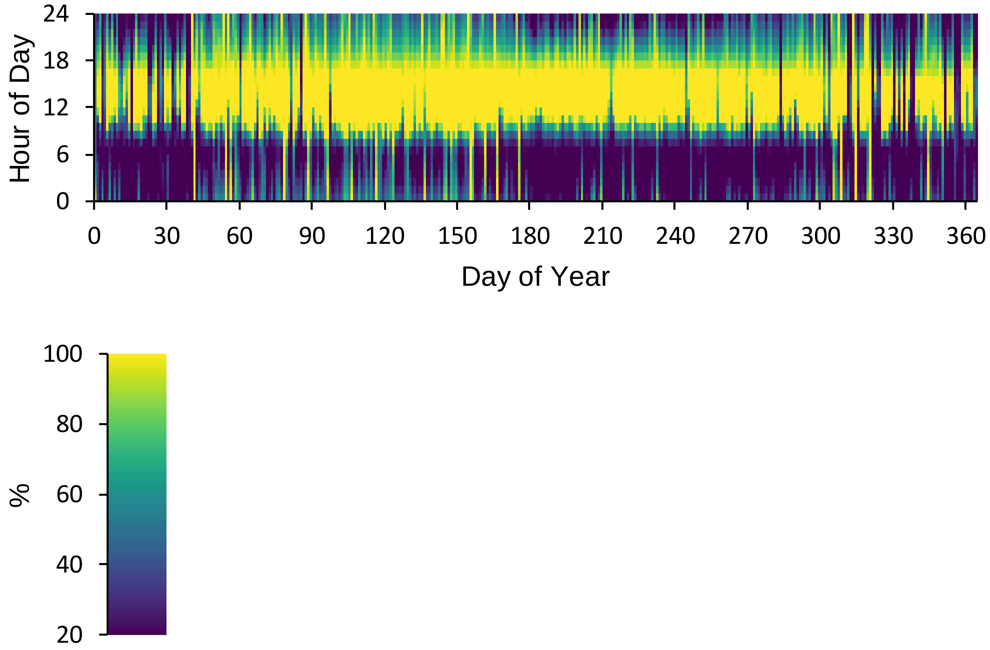
Your Phone Number

Engineering Details



Grid

The annual energy purchased from the grid is 938,867,712 kWh and the annual energy sold to the grid is 1,752,705,664 kWh.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
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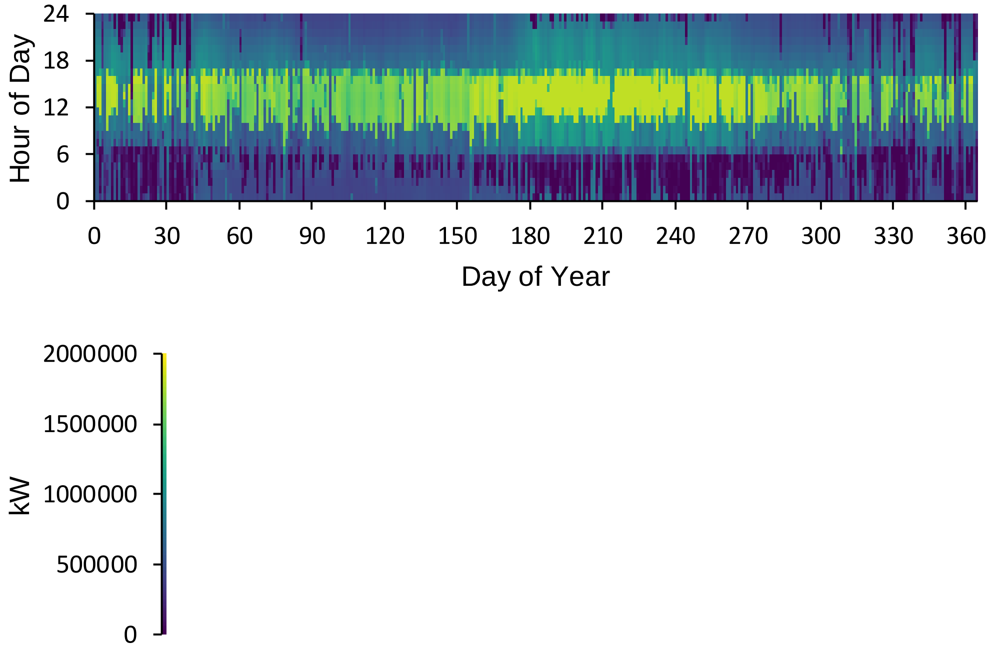
Annual	938,867,712	1,752,705,664	-813,837,952	941,809	-€3.14M	€0.00	-€3.14M

Engineering Details

Converter: System Converter

Capacity	1,818,918 kW	Hours of Operation	8,471 hrs/yr
Mean Output	781,199 kW	Energy Out	6,843,304,960 kWh/yr
Minimum Output	0 kW	Energy In	7,203,478,528 kWh/yr
Maximum Output	1,818,918 kW	Losses	360,173,920 kWh/yr
Capacity Factor	42.9 %		



Cash Flows

Project Lifetime 25 years

Nominal Discount Rate 8.0%

Expected Inflation Rate 2.0%

Real Interest Rate 5.9%

Year	1	2	3	4	5	6	7	8	9	10
biomass	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)
Generic 1MWh Li-Ion	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)
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Year	11	12	13	14	15	16	17	18	19	20
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Glossary and Abbreviations

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- is the yearly cost savings relative to the initial investment. The ROI is the average yearly difference in nominal cash flows over the project lifetime, divided by the difference in capital cost.

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- is the discount rate at which the base case and current system have the same net present cost. HOMER calculates the IRR by determining the discount rate that makes the present value of the difference of the two cash flow sequences equal to zero.

Refer to HOMER Pro Online Help Manual

Abbreviations

GenLarge (12)	biomass
1MLI	Generic 1MWh Li-Ion
PH 245	Generic 245kWh Pumped Hydro
Ves2000	Vestas V90-2.0
SG300MBF	Peimar SG300MBF
Converter	System Converter

About HOMER Pro

HOMER® Pro simulates engineering and economic feasibility of microgrid or distributed energy systems that are off-grid or tied to an unreliable grid and enables the design of least-cost electrical systems and risk-mitigation strategies. The software provides insight into cost-effectively combining conventional and renewable energy, storage, grid resources (where available), and load management.

In a single data run, HOMER Pro simulates the operation of a hybrid microgrid or distributed energy system for an entire year, evaluating and optimizing the electrical system design, load profiles, components, fuel costs, and environmental variables. The simulation produces key information on technical performance, risk-mitigation, and projected cost-savings to inform system design and optimization. Results are presented in a succinct Microgrid Proposal. For more information, visit HomerEnergy.com.

About HOMER Energy by UL

HOMER software is used by more than 200,000 users in 193 different countries.

HOMER Energy by UL is the developer and distributor of HOMER software, a global standard for energy modeling tools that analyze solar-plus-storage, microgrids, and other distributed energy projects.

HOMER software helps engineers and project developers navigate the complexities of designing cost-effective and reliable microgrids that combine traditional and renewable generation sources. The company makes two software platforms: HOMER Pro for the design of least-cost hybrid microgrid or distributed energy systems for use off-grid or when tied to an unreliable grid; and HOMER Grid, which helps design behind-the-meter solar-plus-storage systems to reduce costs and lower carbon footprints.

Since its founding in Boulder, Colorado in 2009, HOMER Energy software has proven effective for analyzing complex distributed energy systems, including grid-tied hybrid renewable microgrids and situations where the grid is insufficiently reliable, such as islands and remote communities. In 2019, HOMER Energy was acquired by UL. More than 200,000 HOMER Pro users in over 190 countries have produced economic feasibility studies, system design, engineering insight, and energy cost savings. Learn more at www.homerenergy.com.

PREPARED BY:
Your Name,
Your Title, Your Company Name,
Your Email,
Your Phone Number

Microgrid Proposal

PREPARED FOR:
Li-ion/PHES_R1o, Li-ion_PHES_R1o
Unnamed Road, Lefkoşa 99040

PREPARED BY:
Your Name, Your Title
Your Company Name, Your Email
Your Phone Number

This proposal was generated using HOMER Pro, a dynamic software engine that runs complex simulations of your hybrid electrical system's energy data and system components to determine the least-cost solution and most effective risk-mitigation strategies. Originally developed at the US Department of Energy's National Renewable Energy Laboratory (NREL), HOMER software set the global standard for optimizing microgrid design. More than 200,000 HOMER Pro users worldwide have produced economic feasibility studies, system design, engineering insight, and energy cost savings.

Table of Contents

Project Summary

CURRENT SYSTEM

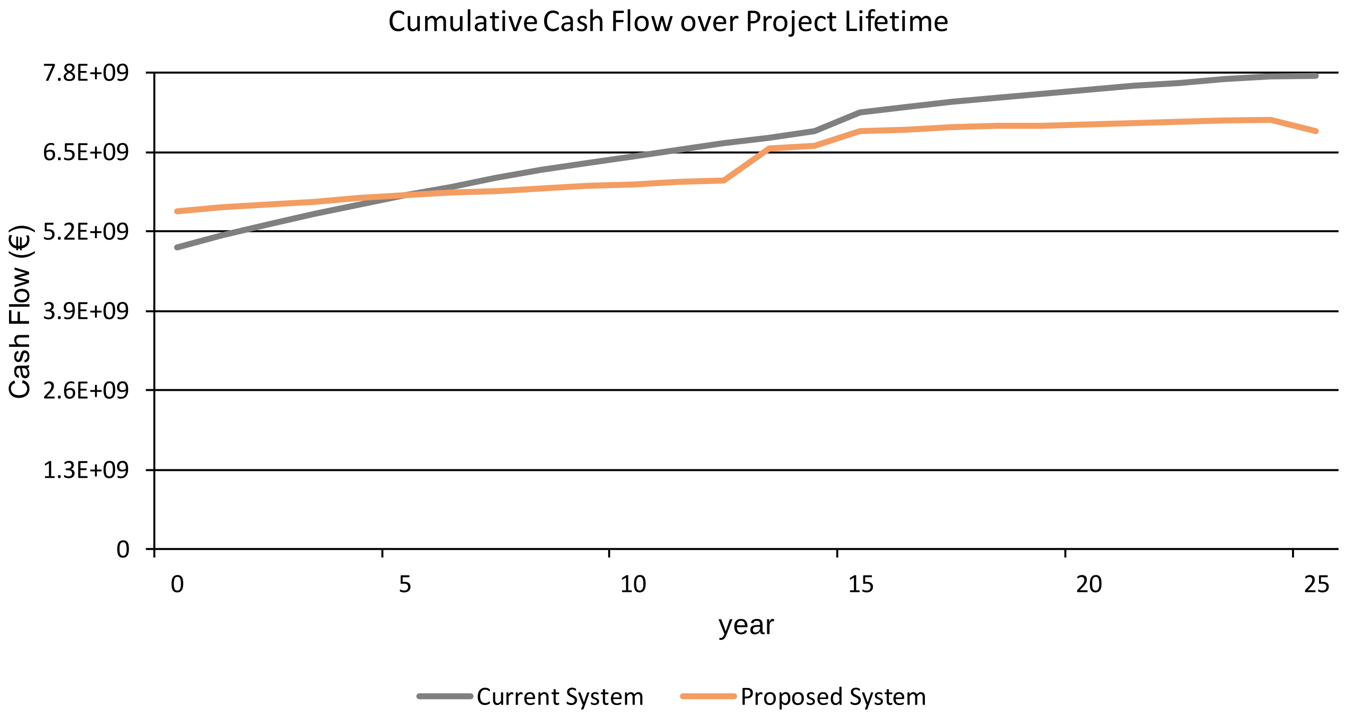
The electric needs of Unnamed Road, Lefkoşa 99040 are met with 90,000 kW of generator capacity, 7,665,212 kWh of battery capacity and 3,408,000 kW of wind generation capacity. Your operating costs for energy are currently €217M per year.

PROPOSED SYSTEM

We propose adding 4,485,800 kW of PV. This would reduce your operating costs to €102M/yr. Your investment has a payback of 4.20 years and an IRR of 21.1%.

Simple payback:	4.20 yr
Return on Investment:	18.0 %
Internal Rate of Return:	21.1 %

Net Present Value:	€902M
Capital Investment:	€590M
Annualized Savings:	€115M



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ABOUT YOUR COMPANY NAME

Use this section to introduce your company name and explain what your business does, where you operate (or the markets you serve), and how long you've been doing it for. About Us page is the ideal place to accommodate several objectives:

- Communicate the story of your business and why you started it.
- Describe the customers or the cause that your business serves.
- Explain your business model or how your products are made

Customer Testimonials

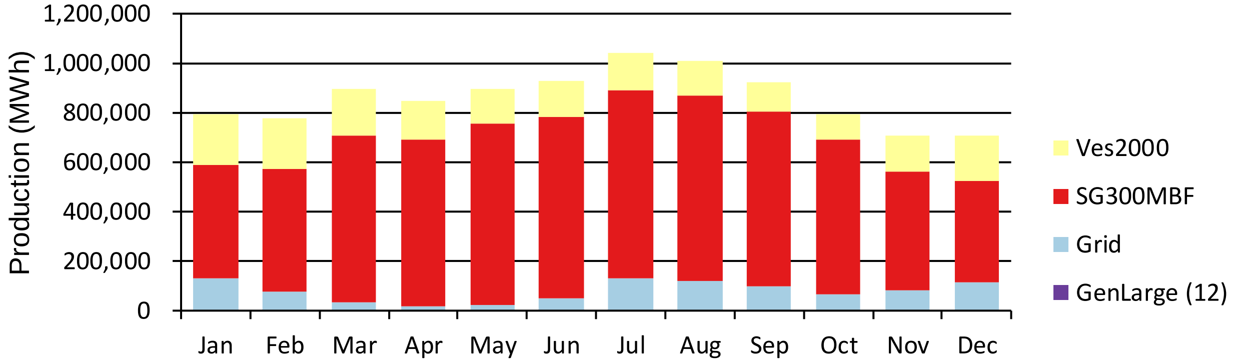
Use this space to provide statements made about your company by satisfied customers. Quotes and positive comments are valuable to prospective clients as they evaluate their options and decide whether your company's services provide the best solution to fit their needs. Testimonial statements demonstrate how others have benefited from your company's services, making them a powerful tool for establishing trust and encouraging potential clients to take action.

—John J. Client, CEO - Your Happy Client, Inc.

Consumption Summary

Electric Consumption

This microgrid requires 21316395 kWh/day and has a peak of 1818918 kW. In the proposed system, the following generation sources serve the electrical load.



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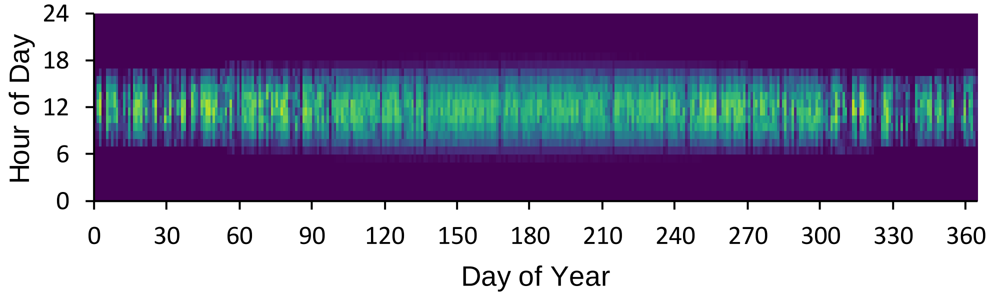
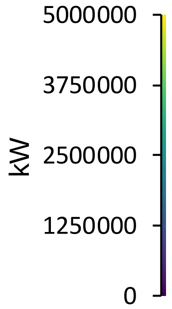
PV: Peimar SG300MBF

The Peimar Inc. PV system has a nominal capacity of 4,485,800 kW. The annual production is 7,501,490,176 kWh/yr.

Rated Capacity	4,485,800 kW
Capital Cost	€2.92B
Specific Yield	1,672 kWh/kW
PV Penetration	124 %

Total Production	7,501,490,176 kW
Maintenance Cost	15,251,719 €/yr
LCOE	0.0309 €/kWh





Wind Turbine: Vestas V90-2.0

Power output from the Vestas wind turbine system, rated at 802,000 kW, is 1,878,918,528 kWh/yr.

Quantity	401
Wind Turbine Total Production	1,878,918,528 kWh/yr
Capital Cost	€802M
Wind Turbine Lifetime	20.0 years

Rated Capacity	802,000 kW
Hours of Operation	7,837 hrs/yr
Maintenance Cost	23,618,900 €/yr

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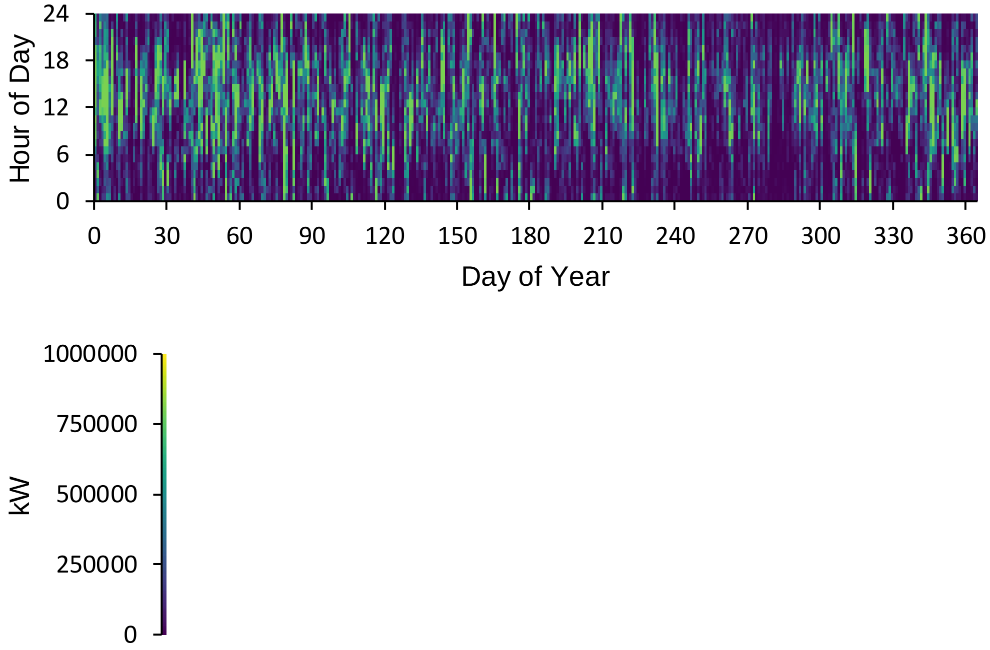

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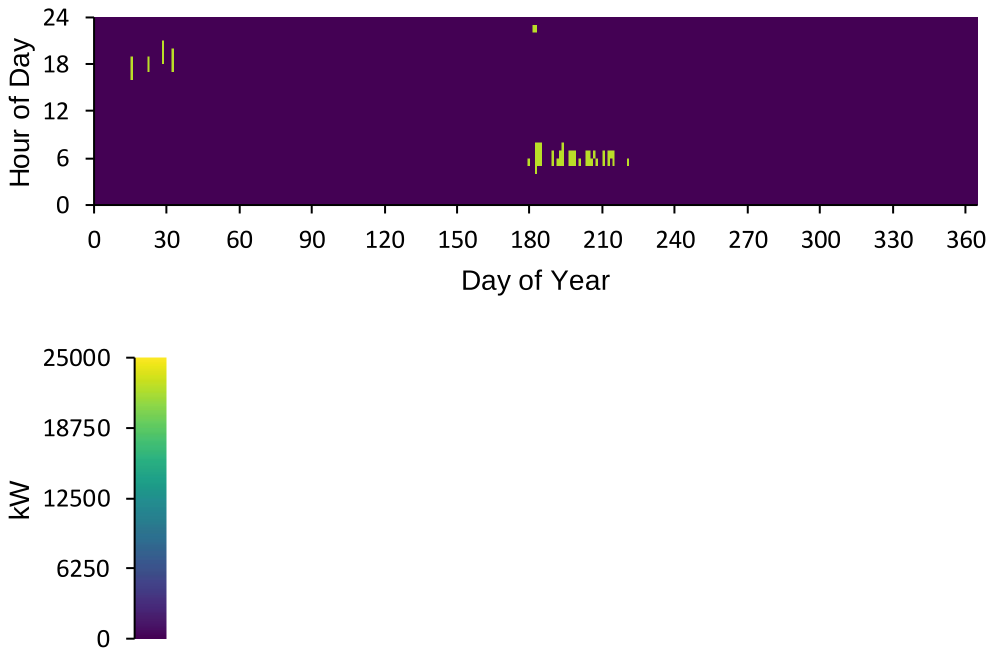
Engineering Details

Generator: biomass (Natural Gas)

Power output from the Generic generator system, rated at 90,000 kW using Natural Gas as fuel, is 1,215,000 kWh/yr.

Capacity	90,000 kW
Operational Life	278 yr
Capital Cost	€306M
Fuel Consumption	72,900 m³
Hours of Operation	54.0 hrs/yr
Fixed Generation Cost	21,291 €/hr

Generator Fuel	Natural Gas
Generator Fuel Price	0.300 €/m³
Maintenance Cost	20,520 €/yr
Electrical Production	1,215,000 kWh/yr
Marginal Generation Cost	0.0989 €/kWh

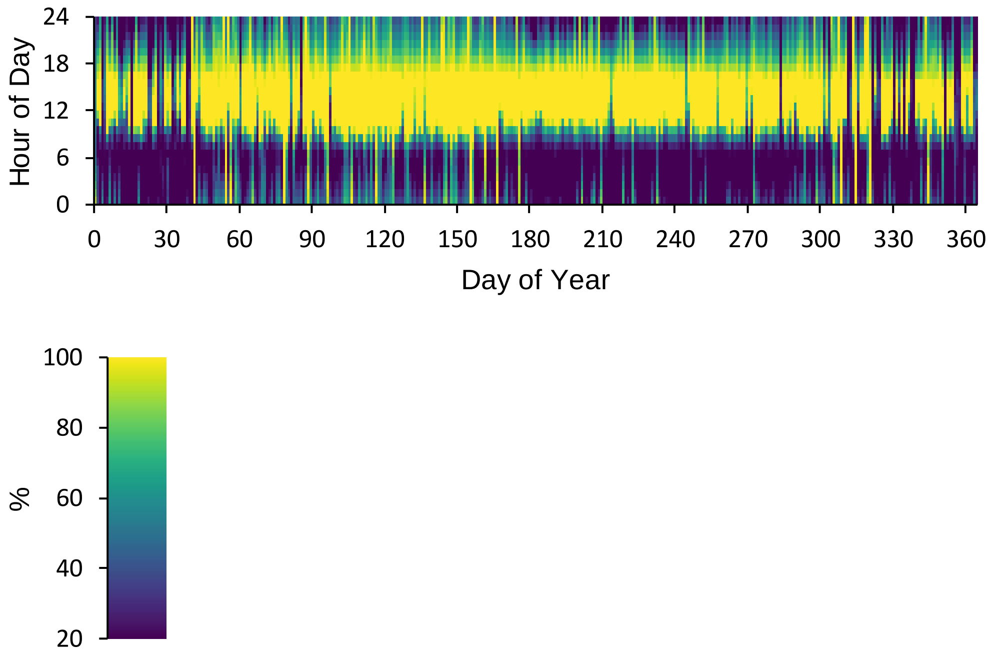


Storage: Generic 1MWh Li-Ion

The Generic storage system's nominal capacity is 6,647,002 kWh. The annual throughput is 1,654,909,056 kWh/yr.

Rated Capacity	6,647,002 kWh
Annual Throughput	1,654,909,056 kWh/yr
Maintenance Cost	24,718,532 €/yr
Autonomy	7.72 hr

Expected Life	12.0 yr
Capital Costs	€959M
Losses	174,155,088 kWh/yr



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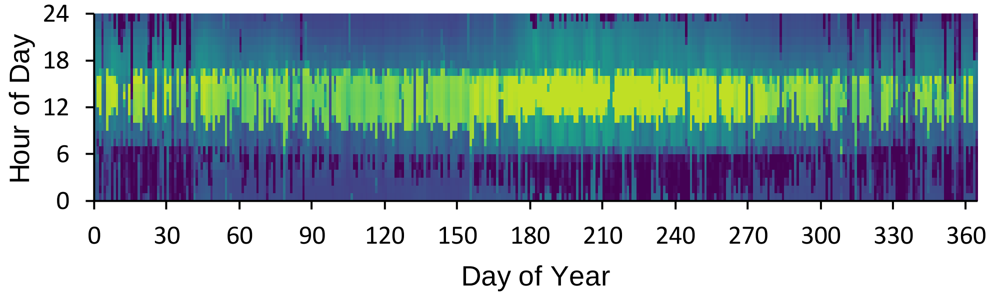

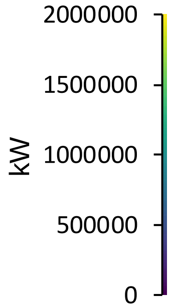

Cash Flows

Project Lifetime	25 years	Expected Inflation Rate	2.0%
Nominal Discount Rate	8.0%	Real Interest Rate	5.9%

Year	1	2	3	4	5	6	7	8	9	10
biomass	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)
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Your Phone Number

About HOMER Pro

HOMER® Pro simulates engineering and economic feasibility of microgrid or distributed energy systems that are off-grid or tied to an unreliable grid and enables the design of least-cost electrical systems and risk-mitigation strategies. The software provides insight into cost-effectively combining conventional and renewable energy, storage, grid resources (where available), and load management.

In a single data run, HOMER Pro simulates the operation of a hybrid microgrid or distributed energy system for an entire year, evaluating and optimizing the electrical system design, load profiles, components, fuel costs, and environmental variables. The simulation produces key information on technical performance, risk-mitigation, and projected cost-savings to inform system design and optimization. Results are presented in a succinct Microgrid Proposal. For more information, visit HomerEnergy.com.

About HOMER Energy by UL

HOMER software is used by more than 200,000 users in 193 different countries.

HOMER Energy by UL is the developer and distributor of HOMER software, a global standard for energy modeling tools that analyze solar-plus-storage, microgrids, and other distributed energy projects.

HOMER software helps engineers and project developers navigate the complexities of designing cost-effective and reliable microgrids that combine traditional and renewable generation sources. The company makes two software platforms: HOMER Pro for the design of least-cost hybrid microgrid or distributed energy systems for use off-grid or when tied to an unreliable grid; and HOMER Grid, which helps design behind-the-meter solar-plus-storage systems to reduce costs and lower carbon footprints.

Since its founding in Boulder, Colorado in 2009, HOMER Energy software has proven effective for analyzing complex distributed energy systems, including grid-tied hybrid renewable microgrids and situations where the grid is insufficiently reliable, such as islands and remote communities. In 2019, HOMER Energy was acquired by UL. More than 200,000 HOMER Pro users in over 190 countries have produced economic feasibility studies, system design, engineering insight, and energy cost savings. Learn more at www.homerenergy.com.

Microgrid Proposal

PREPARED FOR:
Li-ion/PHES_R1e, Li-ion_PHES_R1e
Unnamed Road, Lefkoşa 99040

PREPARED BY:
Your Name, Your Title
Your Company Name, Your Email
Your Phone Number

This proposal was generated using HOMER Pro, a dynamic software engine that runs complex simulations of your hybrid electrical system's energy data and system components to determine the least-cost solution and most effective risk-mitigation strategies. Originally developed at the US Department of Energy's National Renewable Energy Laboratory (NREL), HOMER software set the global standard for optimizing microgrid design. More than 200,000 HOMER Pro users worldwide have produced economic feasibility studies, system design, engineering insight, and energy cost savings.

Table of Contents

PREPARED BY:
Your Name,
Your Title, Your Company Name,
Your Email,
Your Phone Number

Project Summary

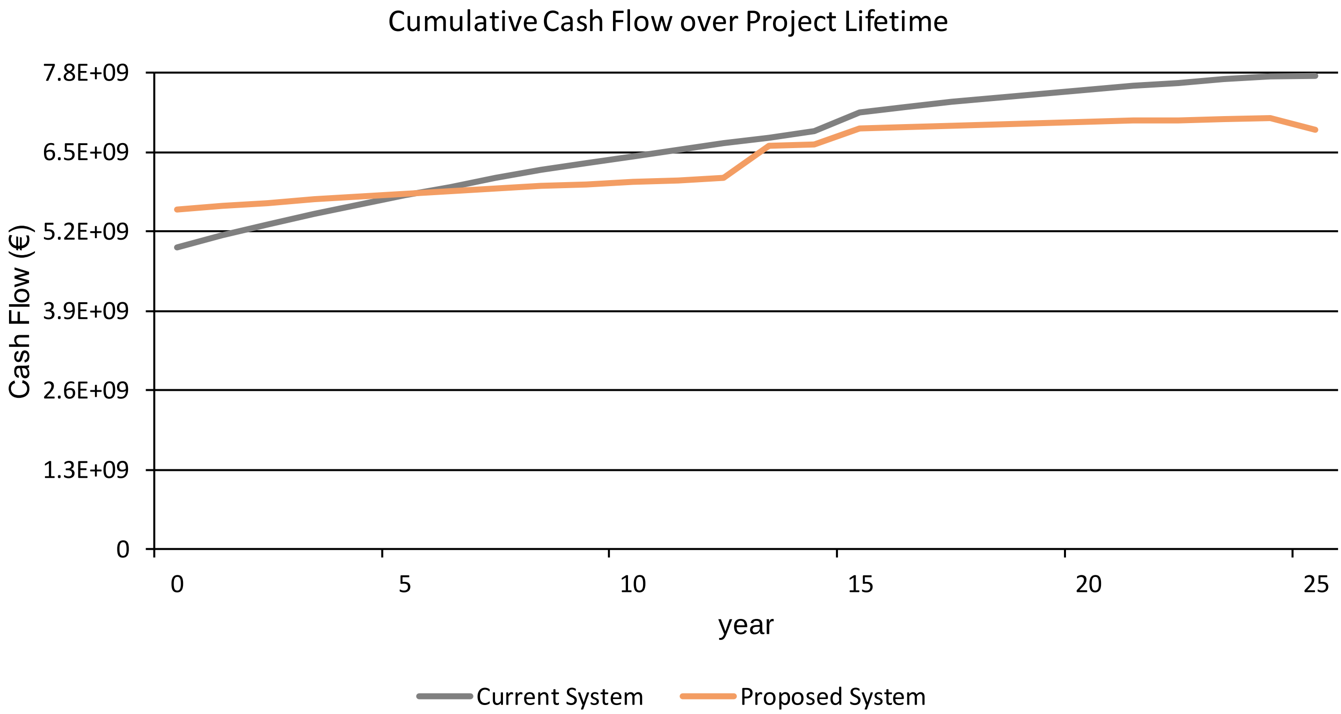
CURRENT SYSTEM

The electric needs of Unnamed Road, Lefkoşa 99040 are met with 90,000 kW of generator capacity, 7,665,212 kWh of battery capacity and 3,408,000 kW of wind generation capacity. Your operating costs for energy are currently €217M per year.

PROPOSED SYSTEM

We propose adding 4,485,800 kW of PV. This would reduce your operating costs to €102M/yr. Your investment has a payback of 4.41 years and an IRR of 19.8%.

Simple payback:	4.41 yr		Net Present Value:	€872M
Return on Investment:	17.0 %		Capital Investment:	€620M
Internal Rate of Return:	19.8 %		Annualized Savings:	€115M



ABOUT YOUR COMPANY NAME

Use this section to introduce your company name and explain what your business does, where you operate (or the markets you serve), and how long you've been doing it for. About Us page is the ideal place to accommodate several objectives:

- Communicate the story of your business and why you started it.
- Describe the customers or the cause that your business serves.
- Explain your business model or how your products are made

Customer Testimonials

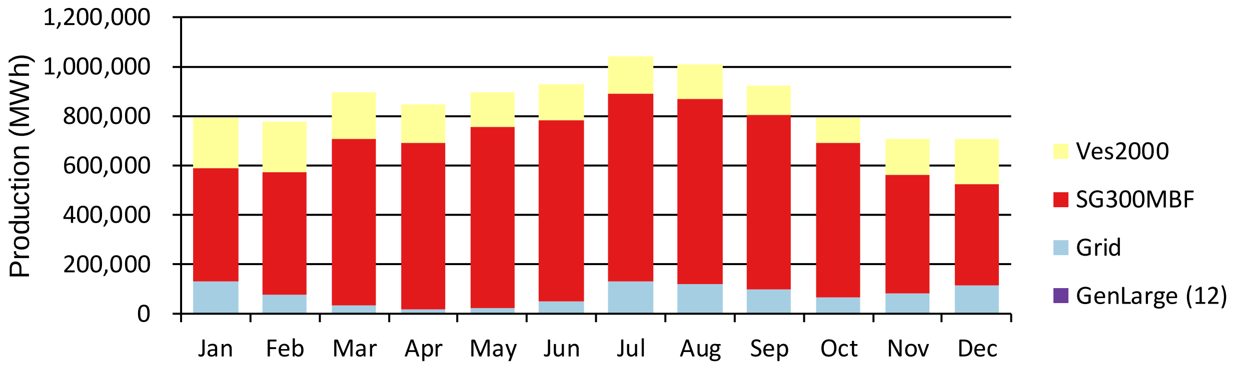
Use this space to provide statements made about your company by satisfied customers. Quotes and positive comments are valuable to prospective clients as they evaluate their options and decide whether your company's services provide the best solution to fit their needs. Testimonial statements demonstrate how others have benefited from your company's services, making them a powerful tool for establishing trust and encouraging potential clients to take action.

—John J. Client, CEO - Your Happy Client, Inc.

Consumption Summary

Electric Consumption

This microgrid requires 21316395 kWh/day and has a peak of 1818918 kW. In the proposed system, the following generation sources serve the electrical load.



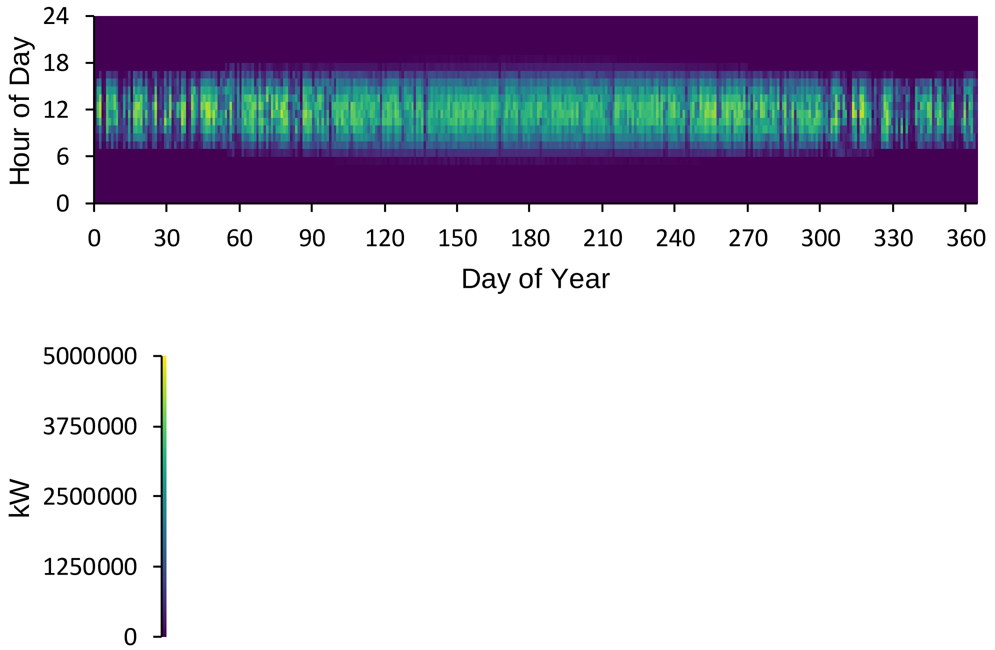
Engineering Details

PV: Peimar SG300MBF

The Peimar Inc. PV system has a nominal capacity of 4,485,800 kW. The annual production is 7,501,490,176 kWh/yr.

Rated Capacity	4,485,800 kW
Capital Cost	€2.92B
Specific Yield	1,672 kWh/kW
PV Penetration	124 %

Total Production	7,501,490,176 kW
Maintenance Cost	15,251,719 €/yr
LCOE	0.0309 €/kWh

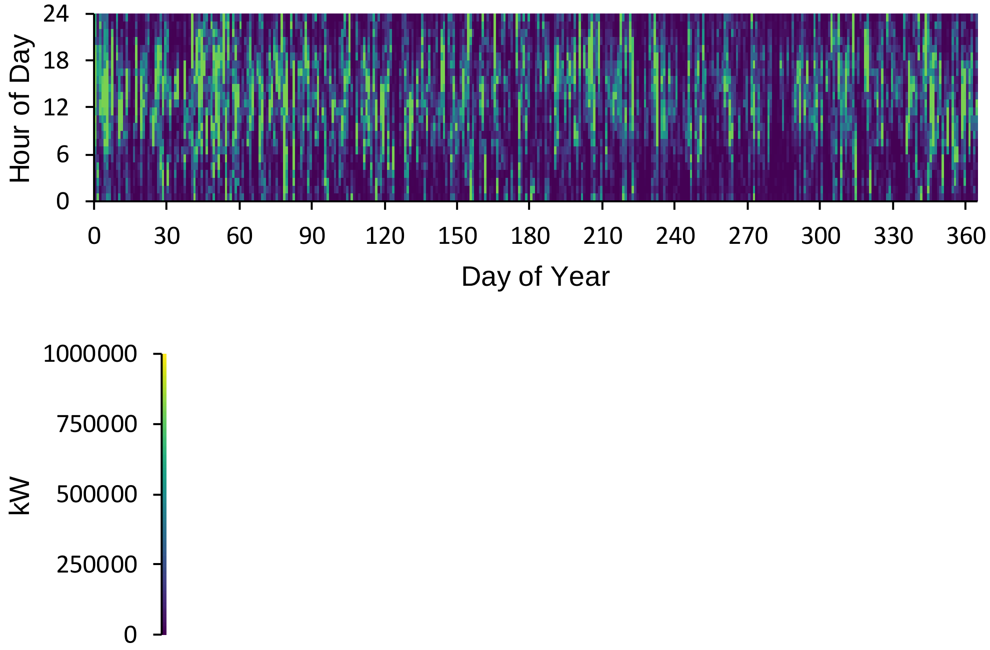


Wind Turbine: Vestas V90-2.0

Power output from the Vestas wind turbine system, rated at 802,000 kW, is 1,878,918,528 kWh/yr.

Quantity	401
Wind Turbine Total Production	1,878,918,528 kWh/yr
Capital Cost	€802M
Wind Turbine Lifetime	20.0 years

Rated Capacity	802,000 kW
Hours of Operation	7,837 hrs/yr
Maintenance Cost	23,618,900 €/yr



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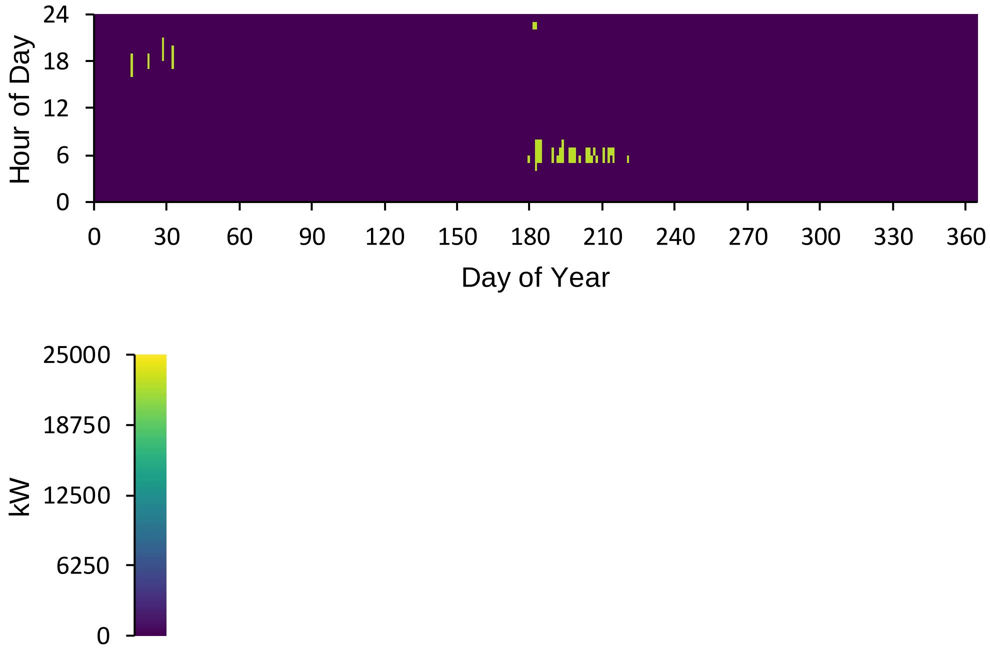
Generator: biomass (Natural Gas)

Power output from the Generic generator system, rated at 90,000 kW using Natural Gas as fuel, is 1,215,000 kWh/yr.

Capacity	90,000 kW
Operational Life	278 yr
Capital Cost	€306M
Fuel Consumption	72,900 m³
Hours of Operation	54.0 hrs/yr
Fixed Generation Cost	21,291 €/hr

Generator Fuel	Natural Gas
Generator Fuel Price	0.300 €/m³
Maintenance Cost	20,520 €/yr
Electrical Production	1,215,000 kWh/yr
Marginal Generation Cost	0.0989 €/kWh



Storage: Generic 1MWh Li-Ion

The Generic storage system's nominal capacity is 6,647,002 kWh. The annual throughput is 1,654,909,056 kWh/yr.

Rated Capacity	6,647,002 kWh
Annual Throughput	1,654,909,056 kWh/yr
Maintenance Cost	24,718,532 €/yr
Autonomy	7.72 hr

Expected Life	12.0 yr
Capital Costs	€989M
Losses	174,155,088 kWh/yr

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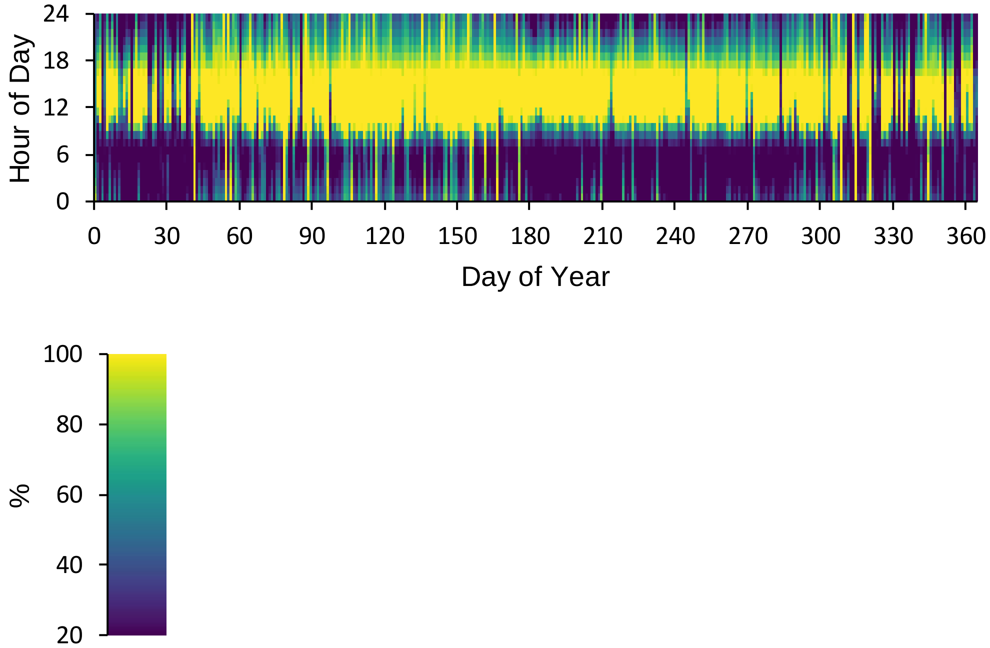


Grid

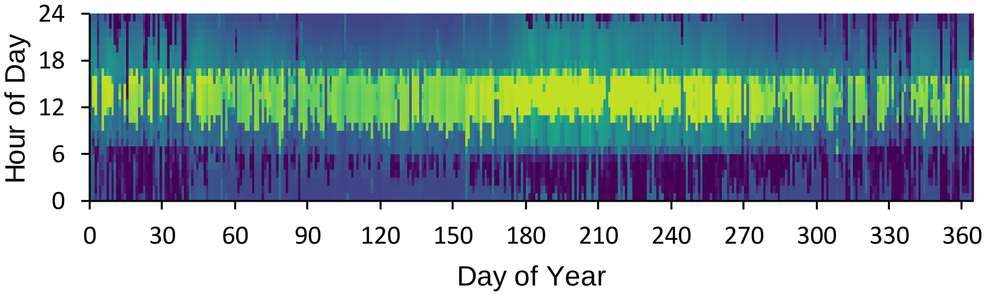
The annual energy purchased from the grid is 938,867,712 kWh and the annual energy sold to the grid is 1,752,705,664 kWh.

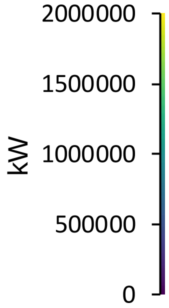
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	129,864,136	91,895,704	37,968,432	941,809	€7.09M	€0.00	€7.09M
February	77,093,072	128,846,600	-51,753,524	934,359	€496,047	€0.00	€496,047
March	36,344,244	176,591,744	-140,247,504	645,738	-€5.56M	€0.00	-€5.56M
April	16,115,042	192,687,696	-176,572,656	602,329	-€8.18M	€0.00	-€8.18M
May	22,485,448	198,308,560	-175,823,120	597,420	-€7.89M	€0.00	-€7.89M
June	47,351,220	185,840,720	-138,489,504	854,443	-€5.03M	€0.00	-€5.03M
July	131,667,976	125,126,720	6,541,254	937,279	€5.59M	€0.00	€5.59M
August	121,848,232	143,575,440	-21,727,206	877,495	€3.79M	€0.00	€3.79M
September	97,526,504	138,833,408	-41,306,904	862,960	€1.84M	€0.00	€1.84M
October	65,087,568	148,222,992	-83,135,424	718,942	-€1.55M	€0.00	-€1.55M
November	80,169,984	127,000,512	-46,830,532	668,660	€865,273	€0.00	€865,273
December	113,314,264	95,775,512	17,538,748	817,408	€5.41M	€0.00	€5.41M
Annual	938,867,712	1,752,705,664	-813,837,952	941,809	-€3.14M	€0.00	-€3.14M

Converter: System Converter

Capacity	1,818,918 kW
Mean Output	781,199 kW
Minimum Output	0 kW
Maximum Output	1,818,918 kW
Capacity Factor	42.9 %

Hours of Operation	8,471 hrs/yr
Energy Out	6,843,304,960 kWh/yr
Energy In	7,203,478,528 kWh/yr
Losses	360,173,920 kWh/yr





Cash Flows

Project Lifetime	25 years	Expected Inflation Rate	2.0%
Nominal Discount Rate	8.0%	Real Interest Rate	5.9%

Year	1	2	3	4	5	6	7	8	9	10
biomass	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)
Generic 1MWh Li-Ion	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)
Grid	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M
Peimar SG300MBF	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)
System Converter	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00
Vestas V90-2.0	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)

Year	11	12	13	14	15	16	17	18	19	20
biomass	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)
Generic 1MWh Li-Ion	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)
Grid	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M
Peimar SG300MBF	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)
System Converter	€0.00	€0.00	€0.00	€0.00	(€546M)	€0.00	€0.00	€0.00	€0.00	€0.00
Vestas V90-2.0	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)

Year	21	22	23	24	25
biomass	(€20,520)	(€20,520)	(€20,520)	(€20,520)	(€20,520)
Generic 1MWh Li-Ion	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)	(€24.7M)
Grid	€3.14M	€3.14M	€3.14M	€3.14M	€3.14M
Peimar SG300MBF	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)	(€15.3M)
System Converter	€0.00	€0.00	€0.00	€0.00	€182M
Vestas V90-2.0	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)	(€23.6M)

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Net Present Value

The total net present cost (NPC) of a system is the present value of all the costs the system incurs over its lifetime, minus the present value of all the revenue it earns over its lifetime. Costs include capital costs, replacement costs, O & M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue. HOMER calculates the total NPC by summing the total discounted cash flows in each year of the project lifetime.

Total Annualized Cost

- is the annualized value of the total net present cost. The annualized cost of a component is the cost that, if it were to occur equally in every year of the project lifetime, would give the same net present cost as the actual cash flow sequence associated with that component. HOMER calculates annualized cost by first calculating the net present cost, then multiplying it by the capital recovery factor.

Simple payback

- is the number of years at which the cumulative cash flow of the difference between the current system and base case system switches from negative to positive. The payback is an indication of how long it would take to recover the difference in investment costs between the current system and the base case system.

Return on Investment (ROI)

- is the yearly cost savings relative to the initial investment. The ROI is the average yearly difference in nominal cash flows over the project lifetime, divided by the difference in capital cost.

Internal rate of return (IRR)

- is the discount rate at which the base case and current system have the same net present cost. HOMER calculates the IRR by determining the discount rate that makes the present value of the difference of the two cash flow sequences equal to zero.

Refer to HOMER Pro Online Help Manual

Abbreviations

GenLarge (12)	biomass
1MLI	Generic 1MWh Li-Ion
PH 245	Generic 245kWh Pumped Hydro
Ves2000	Vestas V90-2.0
SG300MBF	Peimar SG300MBF
Converter	System Converter

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PREPARED FOR:
Flywheel_LeadAcid_Rp,
Flywheel_LeadAcid_R2p
Unnamed Road, Lefkoşa 99040

Microgrid Proposal

PREPARED BY:
Your Name, Your Title
Your Company Name, Your Email
Your Phone Number

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Table of Contents

Project Summary

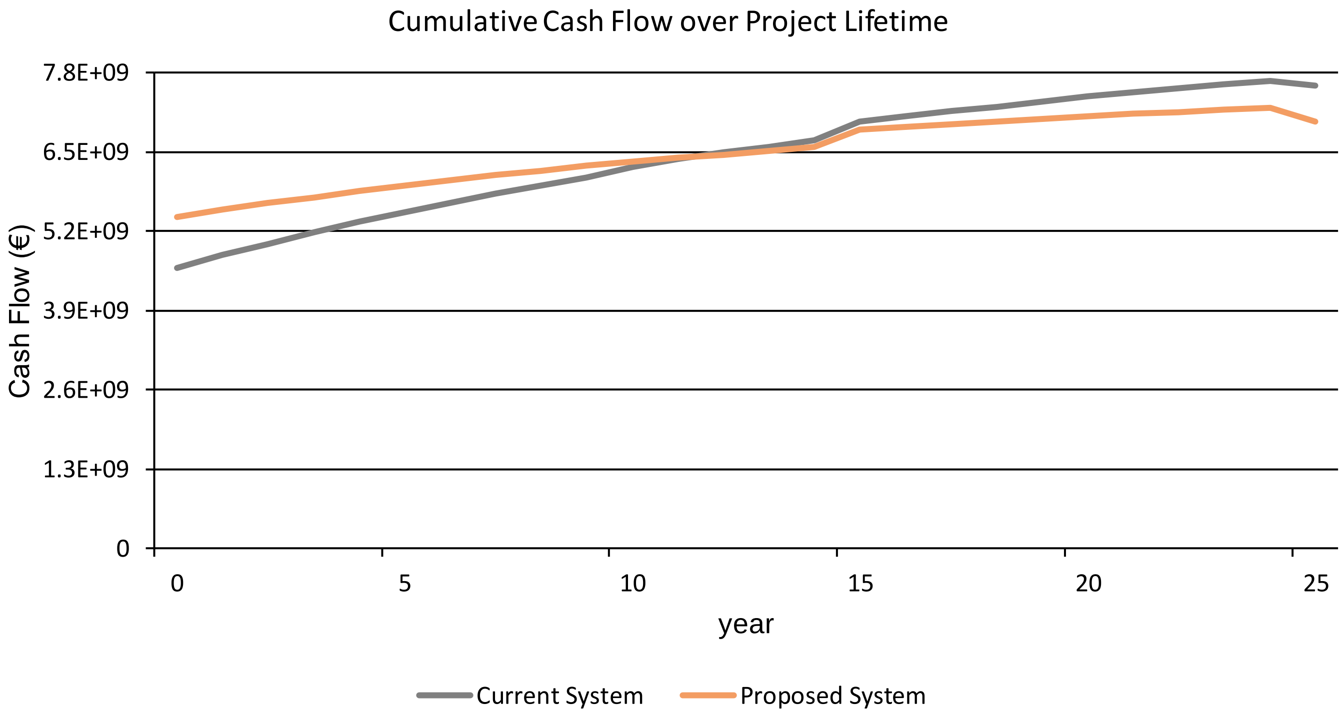
CURRENT SYSTEM

The electric needs of Unnamed Road, Lefkoşa 99040 are met with 90,000 kW of generator capacity, 802,111 kWh of battery capacity and 3,674,000 kW of wind generation capacity. Your operating costs for energy are currently €232M per year.

PROPOSED SYSTEM

We propose adding 6,182,172 kW of PV. This would reduce your operating costs to €121M/yr. Your investment has a payback of 8.77 years and an IRR of 11.7%.

Simple payback:	8.77 yr	Net Present Value:	€605M
Return on Investment:	11.0 %	Capital Investment:	€835M
Internal Rate of Return:	11.7 %	Annualized Savings:	€111M



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—John J. Client, CEO - Your Happy Client, Inc.

PREPARED BY:
Your Name,
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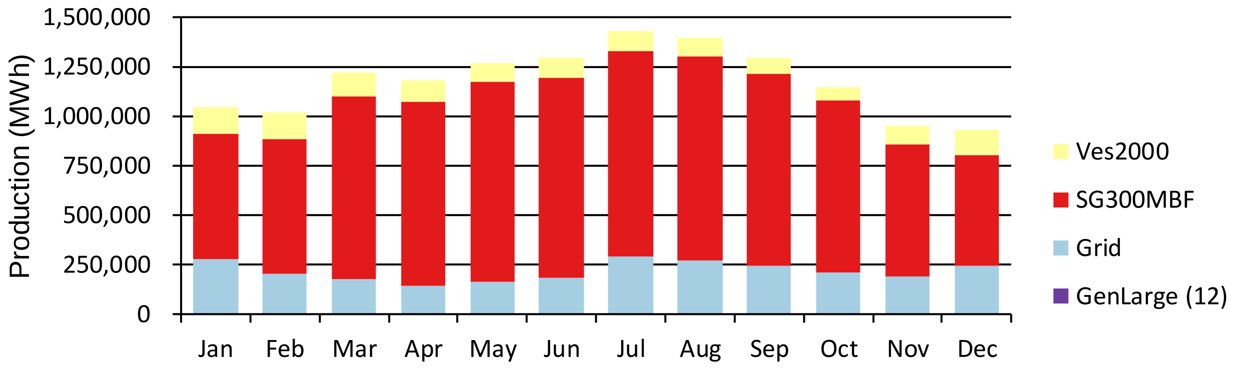
Consumption Summary

Electric Consumption

This microgrid requires 24624267 kWh/day and has a peak of 1912582 kW. In the proposed system, the following generation sources serve the electrical load.

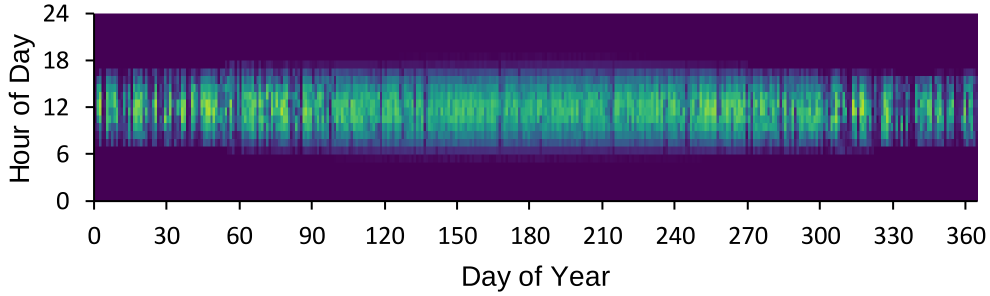


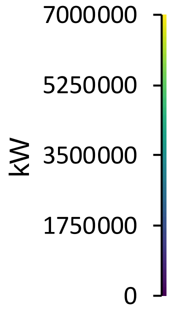
PV: Peimar SG300MBF

The Peimar Inc. PV system has a nominal capacity of 6,182,172 kW. The annual production is 10,338,289,664 kWh/yr.

Rated Capacity	6,182,172 kW
Capital Cost	€4.02B
Specific Yield	1,672 kWh/kW
PV Penetration	171 %

Total Production	10,338,289,664 kW
Maintenance Cost	21,019,384 €/yr
LCOE	0.0309 €/kWh



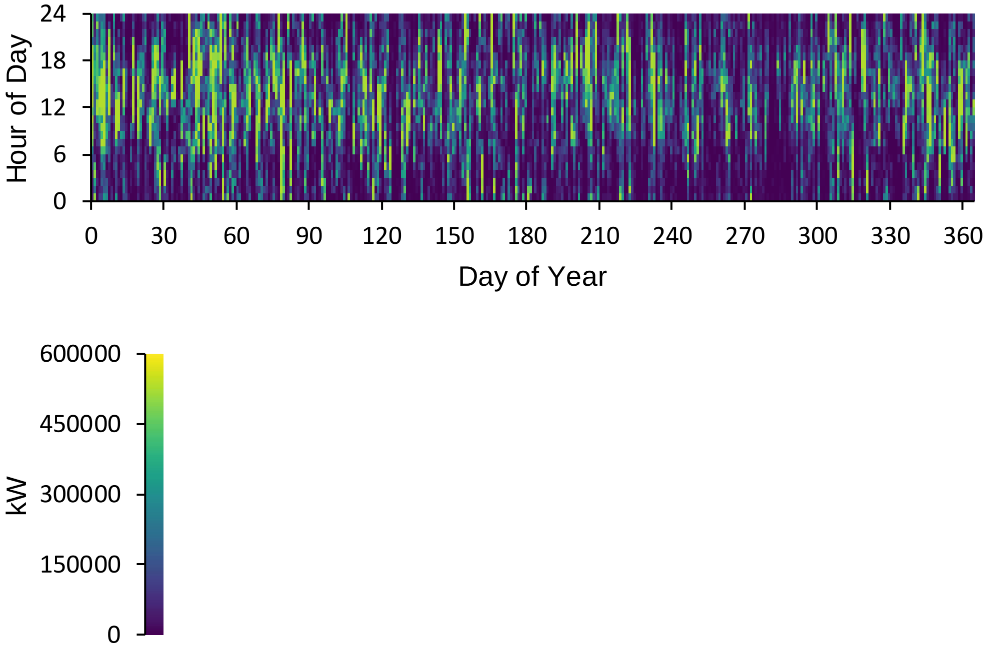


Wind Turbine: Vestas V90-2.0

Power output from the Vestas wind turbine system, rated at 532,000 kW, is 1,246,364,928 kWh/yr.

Quantity	266
Wind Turbine Total Production	1,246,364,928 kWh/yr
Capital Cost	€532M
Wind Turbine Lifetime	20.0 years

Rated Capacity	532,000 kW
Hours of Operation	7,837 hrs/yr
Maintenance Cost	15,667,400 €/yr



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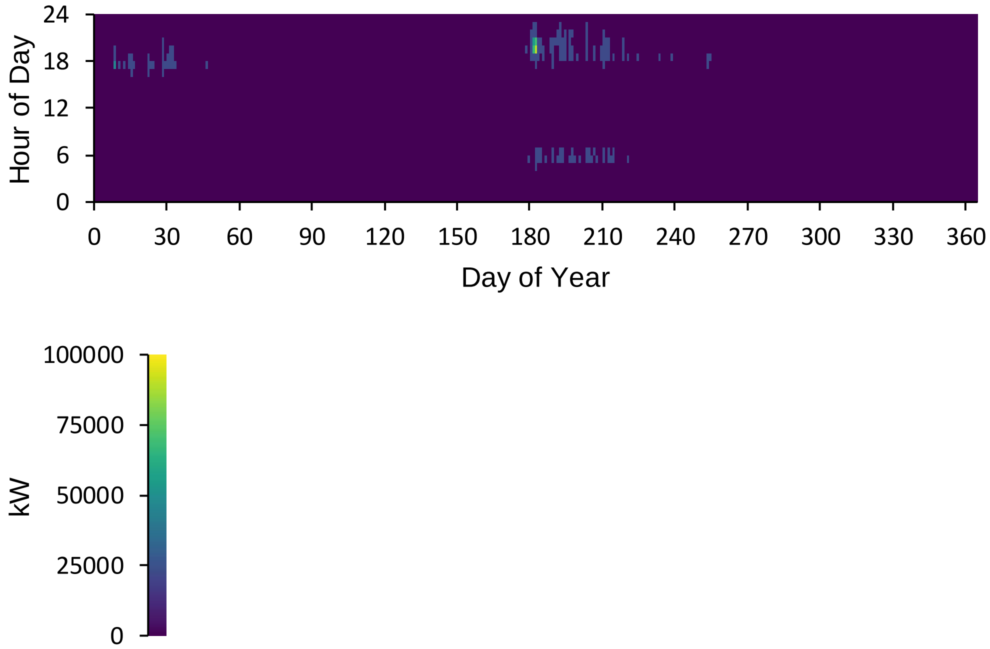
Generator: biomass (Natural Gas)

Power output from the Generic generator system, rated at 90,000 kW using Natural Gas as fuel, is 3,610,660 kWh/yr.

Capacity	90,000 kW
Operational Life	99.3 yr
Capital Cost	€306M
Fuel Consumption	221,520 m³
Hours of Operation	151 hrs/yr
Fixed Generation Cost	21,295 €/hr

Generator Fuel	Natural Gas
Generator Fuel Price	0.300 €/m³
Maintenance Cost	57,984 €/yr
Electrical Production	3,610,660 kWh/yr
Marginal Generation Cost	0.0989 €/kWh



Grid

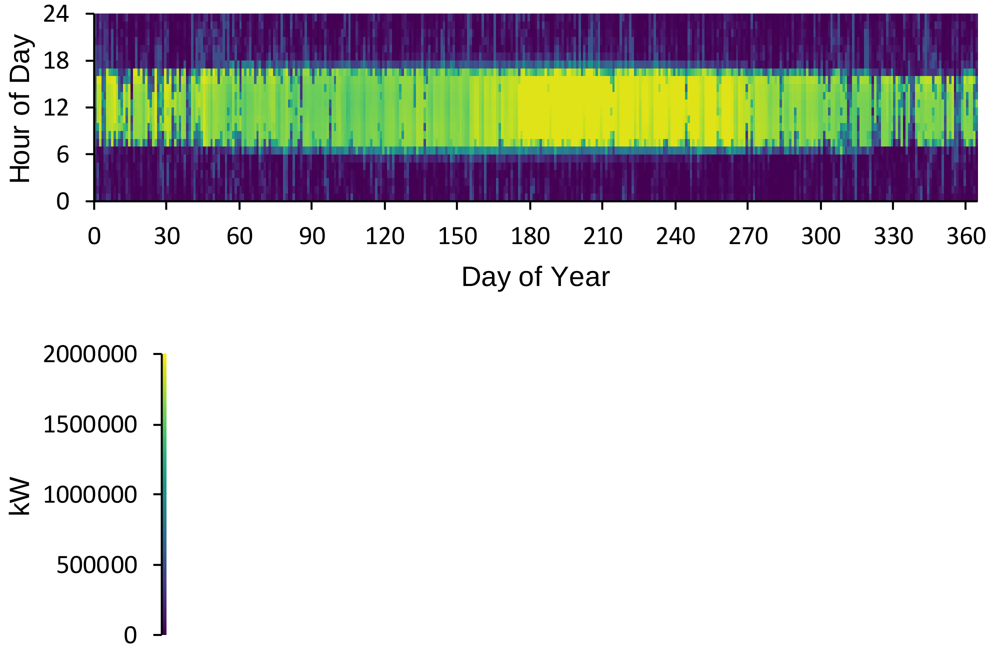
The annual energy purchased from the grid is 2,586,987,520 kWh and the annual energy sold to the grid is 2,961,475,072 kWh.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	275,971,648	185,110,384	90,861,264	1,000,000	€15.6M	€0.00	€15.6M
February	202,220,240	208,090,944	-5,870,705	982,883	€7.80M	€0.00	€7.80M
March	174,538,944	270,466,752	-95,927,816	853,500	€2.19M	€0.00	€2.19M
April	146,234,880	288,466,976	-142,232,080	687,995	-€1.26M	€0.00	-€1.26M
May	161,063,056	303,864,672	-142,801,616	657,497	-€697,558	€0.00	-€697,558
June	182,985,984	287,208,128	-104,222,136	889,042	€2.11M	€0.00	€2.11M
July	286,822,560	246,236,320	40,586,232	1,000,000	€13.5M	€0.00	€13.5M
August	273,063,936	270,579,008	2,484,945	976,941	€11.0M	€0.00	€11.0M
September	241,174,576	257,837,632	-16,663,044	928,924	€8.81M	€0.00	€8.81M
October	211,848,944	259,995,040	-48,146,092	774,230	€6.07M	€0.00	€6.07M
November	188,724,528	202,622,528	-13,898,011	806,470	€6.85M	€0.00	€6.85M
December	242,338,352	180,996,800	61,341,552	885,048	€12.8M	€0.00	€12.8M
Annual	2,586,987,520	2,961,475,072	-374,487,520	1,000,000	€84.8M	€0.00	€84.8M

Converter: System Converter

Capacity	1,912,582 kW
Mean Output	730,795 kW
Minimum Output	0 kW
Maximum Output	1,912,582 kW
Capacity Factor	38.2 %

Hours of Operation	8,122 hrs/yr
Energy Out	6,401,763,840 kWh/yr
Energy In	6,738,698,752 kWh/yr
Losses	336,934,944 kWh/yr



Cash Flows

Project Lifetime	25 years	Expected Inflation Rate	2.0%
Nominal Discount Rate	8.0%	Real Interest Rate	5.9%

Year	1	2	3	4	5	6	7	8	9	10
ABB PowerStore Flywheel	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00
biomass	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)
Grid	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)
Peimar SG300MBF	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)
System Converter	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00
Vestas V90-2.0	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)

Year	11	12	13	14	15	16	17	18	19	20
ABB PowerStore Flywheel	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	(€6,000)
biomass	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)
Grid	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)
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System Converter	€0.00	€0.00	€0.00	€0.00	(€574M)	€0.00	€0.00	€0.00	€0.00	€0.00
Vestas V90-2.0	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)

Year	21	22	23	24	25
ABB PowerStore Flywheel	€0.00	€0.00	€0.00	€0.00	€4,500
biomass	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)
Grid	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)
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System Converter	€0.00	€0.00	€0.00	€0.00	€191M
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Net Present Value

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Total Annualized Cost

- is the annualized value of the total net present cost. The annualized cost of a component is the cost that, if it were to occur equally in every year of the project lifetime, would give the same net present cost as the actual cash flow sequence associated with that component. HOMER calculates annualized cost by first calculating the net present cost, then multiplying it by the capital recovery factor.

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- is the number of years at which the cumulative cash flow of the difference between the current system and base case system switches from negative to positive. The payback is an indication of how long it would take to recover the difference in investment costs between the current system and the base case system.

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Abbreviations

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Your Name,
Your Title, Your Company Name,
Your Email,
Your Phone Number

Microgrid Proposal

PREPARED FOR:
Flywheel_LeadAcid_R2o,
Flywheel_LeadAcid_R2o
Unnamed Road, Lefkoşa 99040

PREPARED BY:
Your Name, Your Title
Your Company Name, Your Email
Your Phone Number

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HOMER Pro

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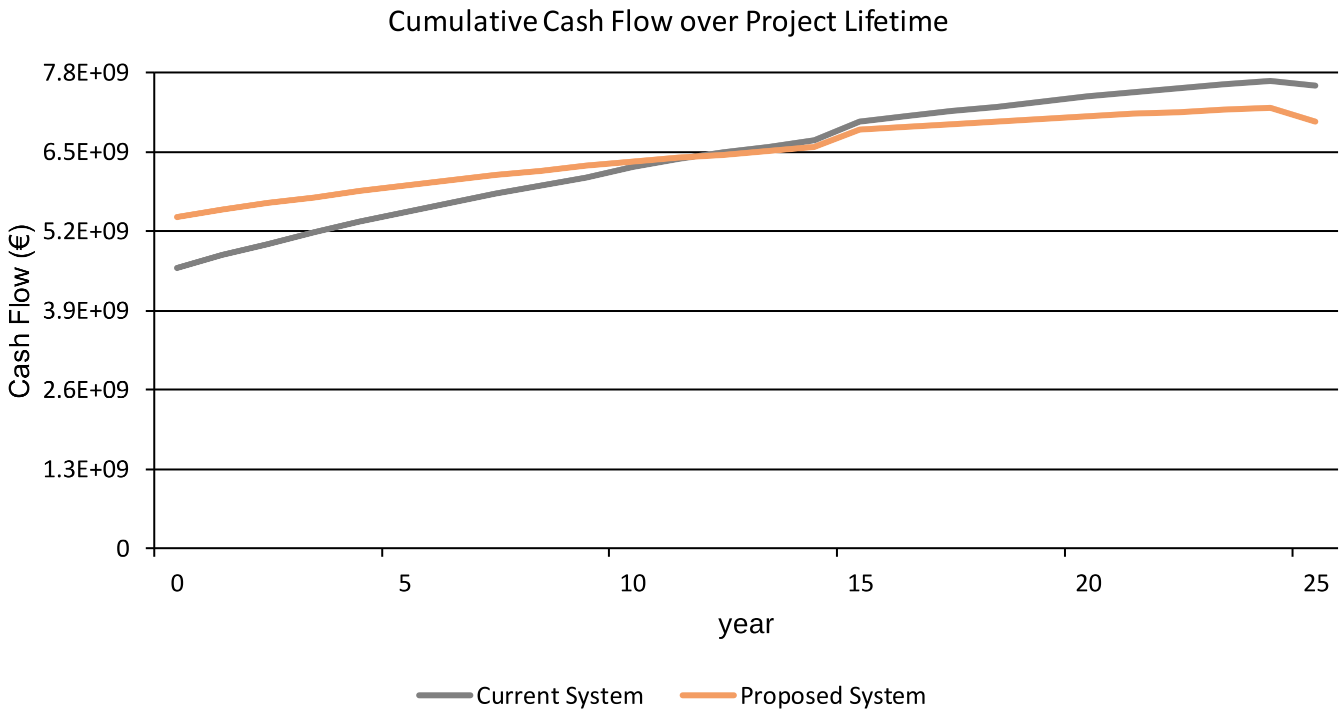
CURRENT SYSTEM

The electric needs of Unnamed Road, Lefkoşa 99040 are met with 90,000 kW of generator capacity, 802,111 kWh of battery capacity and 3,674,000 kW of wind generation capacity. Your operating costs for energy are currently €232M per year.

PROPOSED SYSTEM

We propose adding 6,182,172 kW of PV. This would reduce your operating costs to €121M/yr. Your investment has a payback of 8.77 years and an IRR of 11.7%.

Simple payback:	8.77 yr	Net Present Value:	€605M
Return on Investment:	11.0 %	Capital Investment:	€835M
Internal Rate of Return:	11.7 %	Annualized Savings:	€111M



ABOUT YOUR COMPANY NAME

Use this section to introduce your company name and explain what your business does, where you operate (or the markets you serve), and how long you've been doing it for. About Us page is the ideal place to accommodate several objectives:

- Communicate the story of your business and why you started it.
- Describe the customers or the cause that your business serves.
- Explain your business model or how your products are made

Customer Testimonials

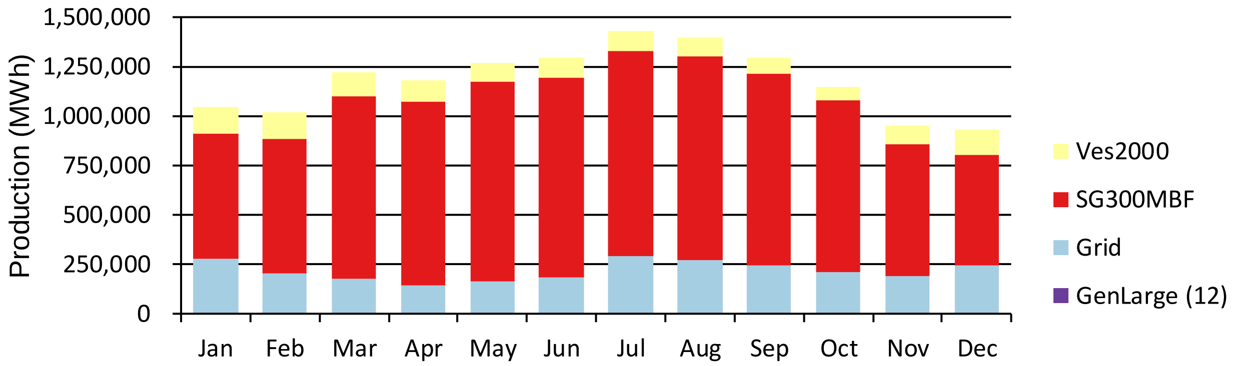
Use this space to provide statements made about your company by satisfied customers. Quotes and positive comments are valuable to prospective clients as they evaluate their options and decide whether your company's services provide the best solution to fit their needs. Testimonial statements demonstrate how others have benefited from your company's services, making them a powerful tool for establishing trust and encouraging potential clients to take action.

—John J. Client, CEO - Your Happy Client, Inc.

Consumption Summary

Electric Consumption

This microgrid requires 24624267 kWh/day and has a peak of 1912582 kW. In the proposed system, the following generation sources serve the electrical load.



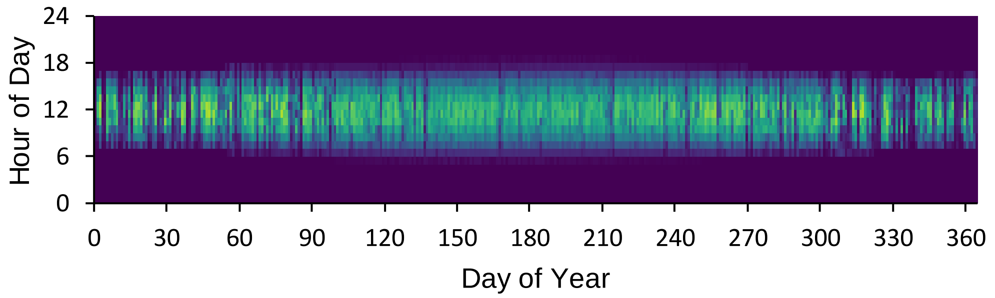
Engineering Details

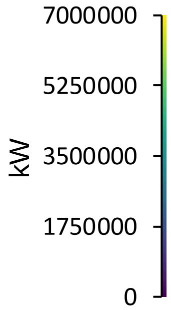
PV: Peimar SG300MBF

The Peimar Inc. PV system has a nominal capacity of 6,182,172 kW. The annual production is 10,338,289,664 kWh/yr.

Rated Capacity	6,182,172 kW
Capital Cost	€4.02B
Specific Yield	1,672 kWh/kW
PV Penetration	171 %

Total Production	10,338,289,664 kW
Maintenance Cost	21,019,384 €/yr
LCOE	0.0309 €/kWh



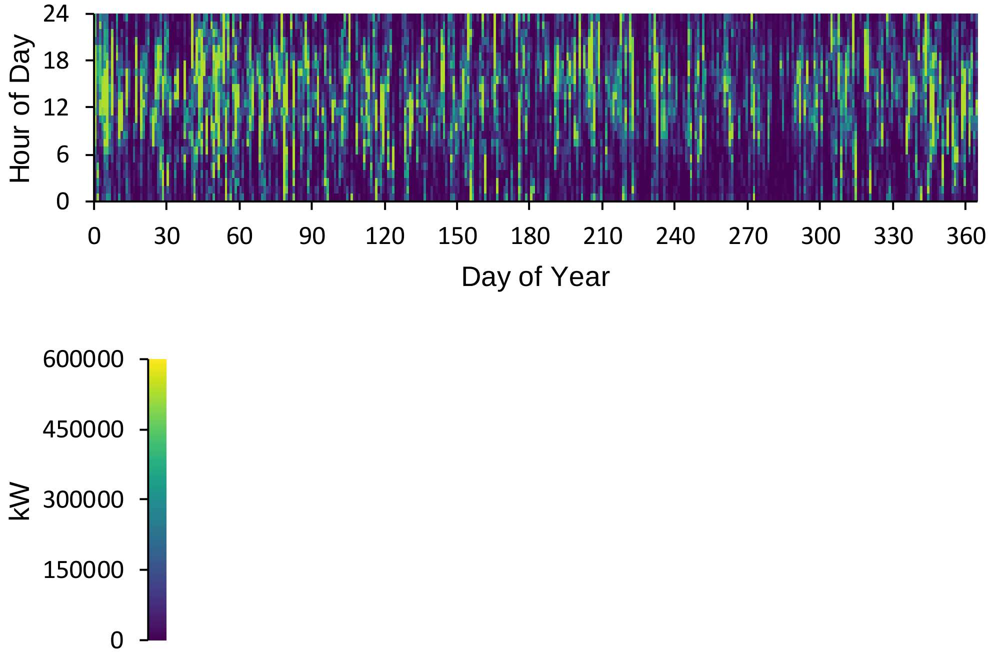


Wind Turbine: Vestas V90-2.0

Power output from the Vestas wind turbine system, rated at 532,000 kW, is 1,246,364,928 kWh/yr.

Quantity	266
Wind Turbine Total Production	1,246,364,928 kWh/yr
Capital Cost	€532M
Wind Turbine Lifetime	20.0 years

Rated Capacity	532,000 kW
Hours of Operation	7,837 hrs/yr
Maintenance Cost	15,667,400 €/yr

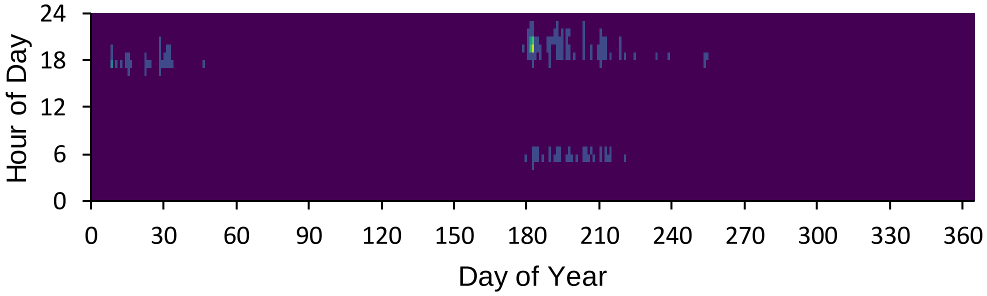

24
18
12
6
0
Hour of Day
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of Year
600000
450000
300000
150000
0
kW

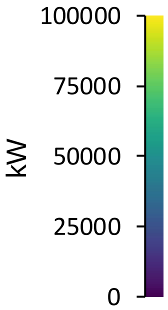
Generator: biomass (Natural Gas)

Power output from the Generic generator system, rated at 90,000 kW using Natural Gas as fuel, is 3,610,660 kWh/yr.

Capacity	90,000 kW
Operational Life	99.3 yr
Capital Cost	€306M
Fuel Consumption	221,520 m³
Hours of Operation	151 hrs/yr
Fixed Generation Cost	21,295 €/hr

Generator Fuel	Natural Gas
Generator Fuel Price	0.300 €/m³
Maintenance Cost	57,984 €/yr
Electrical Production	3,610,660 kWh/yr
Marginal Generation Cost	0.0989 €/kWh





Grid

The annual energy purchased from the grid is 2,586,987,520 kWh and the annual energy sold to the grid is 2,961,475,072 kWh.

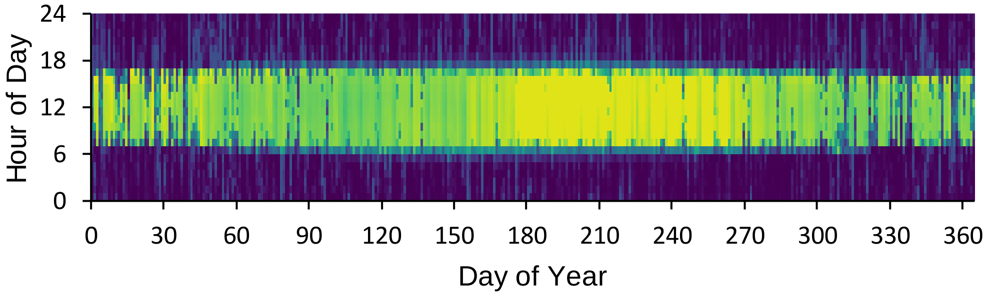
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	275,971,648	185,110,384	90,861,264	1,000,000	€15.6M	€0.00	€15.6M
February	202,220,240	208,090,944	-5,870,705	982,883	€7.80M	€0.00	€7.80M
March	174,538,944	270,466,752	-95,927,816	853,500	€2.19M	€0.00	€2.19M
April	146,234,880	288,466,976	-142,232,080	687,995	-€1.26M	€0.00	-€1.26M
May	161,063,056	303,864,672	-142,801,616	657,497	-€697,558	€0.00	-€697,558
June	182,985,984	287,208,128	-104,222,136	889,042	€2.11M	€0.00	€2.11M
July	286,822,560	246,236,320	40,586,232	1,000,000	€13.5M	€0.00	€13.5M
August	273,063,936	270,579,008	2,484,945	976,941	€11.0M	€0.00	€11.0M
September	241,174,576	257,837,632	-16,663,044	928,924	€8.81M	€0.00	€8.81M
October	211,848,944	259,995,040	-48,146,092	774,230	€6.07M	€0.00	€6.07M
November	188,724,528	202,622,528	-13,898,011	806,470	€6.85M	€0.00	€6.85M
December	242,338,352	180,996,800	61,341,552	885,048	€12.8M	€0.00	€12.8M
Annual	2,586,987,520	2,961,475,072	-374,487,520	1,000,000	€84.8M	€0.00	€84.8M

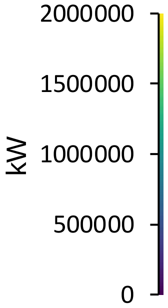
Engineering Details

Converter: System Converter

Capacity	1,912,582 kW
Mean Output	730,795 kW
Minimum Output	0 kW
Maximum Output	1,912,582 kW
Capacity Factor	38.2 %

Hours of Operation	8,122 hrs/yr
Energy Out	6,401,763,840 kWh/yr
Energy In	6,738,698,752 kWh/yr
Losses	336,934,944 kWh/yr





Cash Flows

Project Lifetime 25 years

Nominal Discount Rate 8.0%

Expected Inflation Rate 2.0%

Real Interest Rate 5.9%

Year	1	2	3	4	5	6	7	8	9	10
ABB PowerStore Flywheel	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00
biomass	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)
Grid	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)
Peimar SG300MBF	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)
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Year	11	12	13	14	15	16	17	18	19	20
ABB PowerStore Flywheel	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	(€6,000)
biomass	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)
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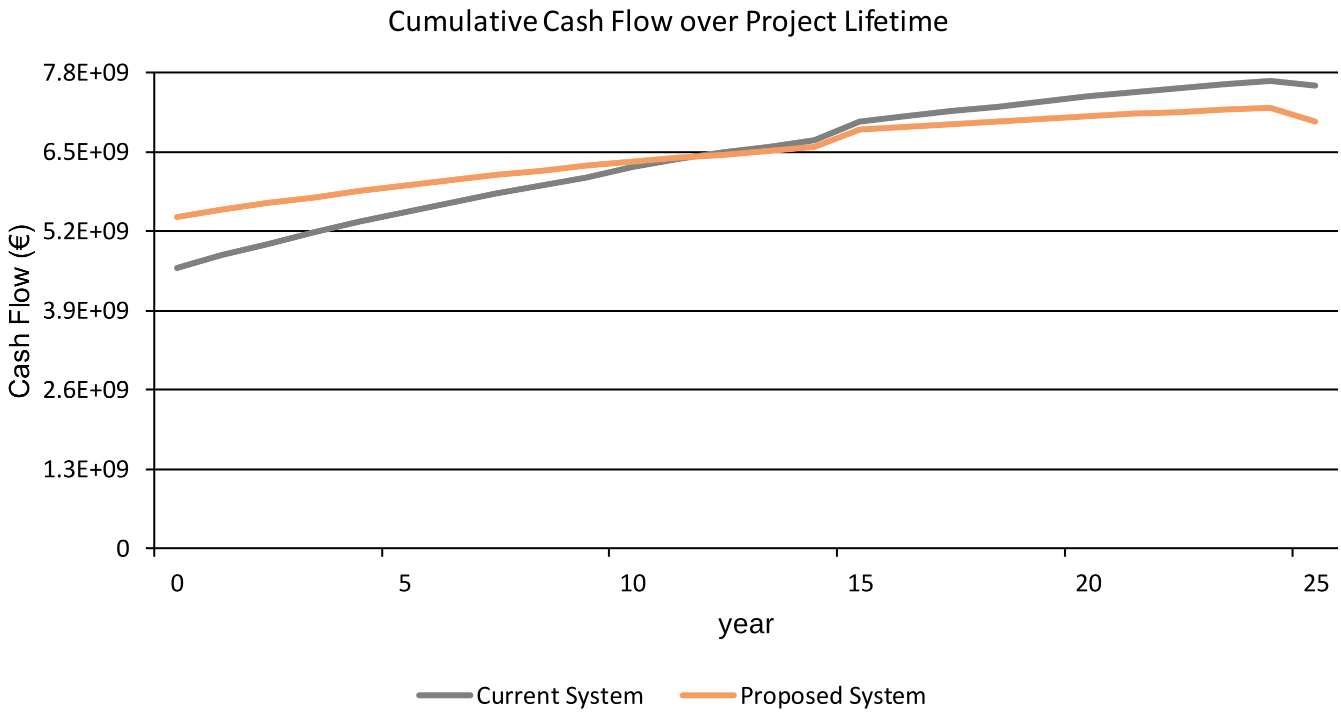


ABOUT YOUR COMPANY NAME

Use this section to introduce your company name and explain what your business does, where you operate (or the markets you serve), and how long you've been doing it for. About Us page is the ideal place to accommodate several objectives:

- Communicate the story of your business and why you started it.
- Describe the customers or the cause that your business serves.
- Explain your business model or how your products are made

Customer Testimonials

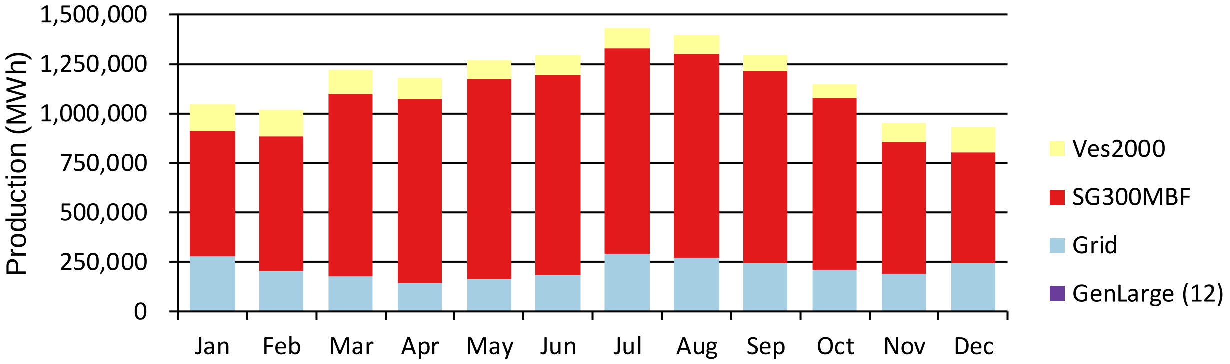
Use this space to provide statements made about your company by satisfied customers. Quotes and positive comments are valuable to prospective clients as they evaluate their options and decide whether your company's services provide the best solution to fit their needs. Testimonial statements demonstrate how others have benefited from your company's services, making them a powerful tool for establishing trust and encouraging potential clients to take action.

—John J. Client, CEO - Your Happy Client, Inc.

Consumption Summary

Electric Consumption

This microgrid requires 24624267 kWh/day and has a peak of 1912582 kW. In the proposed system, the following generation sources serve the electrical load.

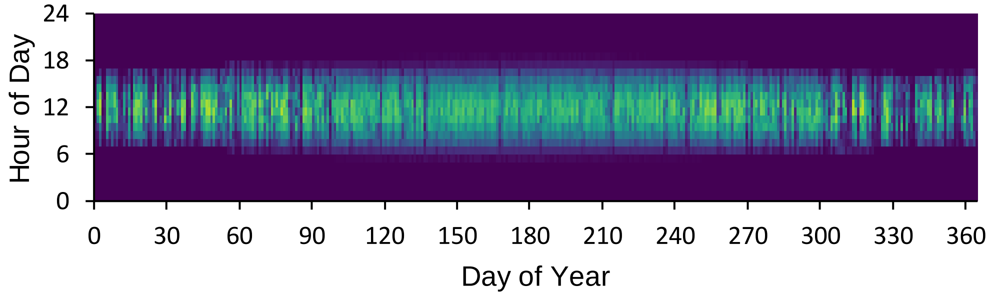


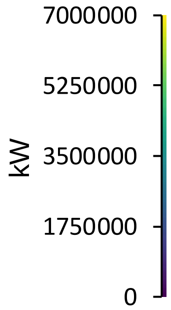
PV: Peimar SG300MBF

The Peimar Inc. PV system has a nominal capacity of 6,182,172 kW. The annual production is 10,338,289,664 kWh/yr.

Rated Capacity	6,182,172 kW
Capital Cost	€4.02B
Specific Yield	1,672 kWh/kW
PV Penetration	171 %

Total Production	10,338,289,664 kW
Maintenance Cost	21,019,384 €/yr
LCOE	0.0309 €/kWh





Wind Turbine: Vestas V90-2.0

Power output from the Vestas wind turbine system, rated at 532,000 kW, is 1,246,364,928 kWh/yr.

Quantity	266
Wind Turbine Total Production	1,246,364,928 kWh/yr
Capital Cost	€532M
Wind Turbine Lifetime	20.0 years

Rated Capacity	532,000 kW
Hours of Operation	7,837 hrs/yr
Maintenance Cost	15,667,400 €/yr

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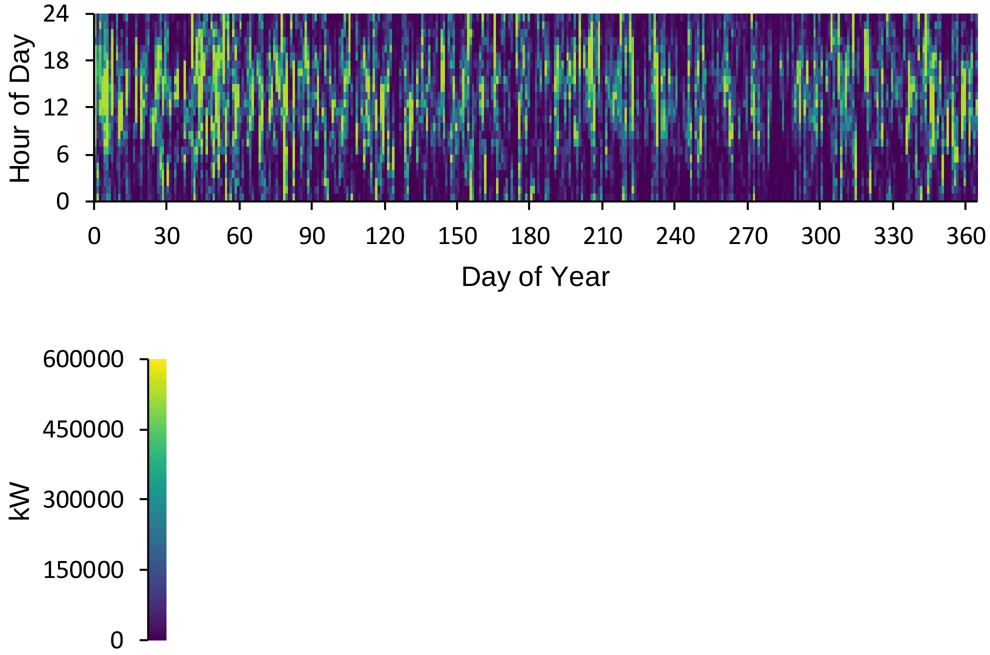
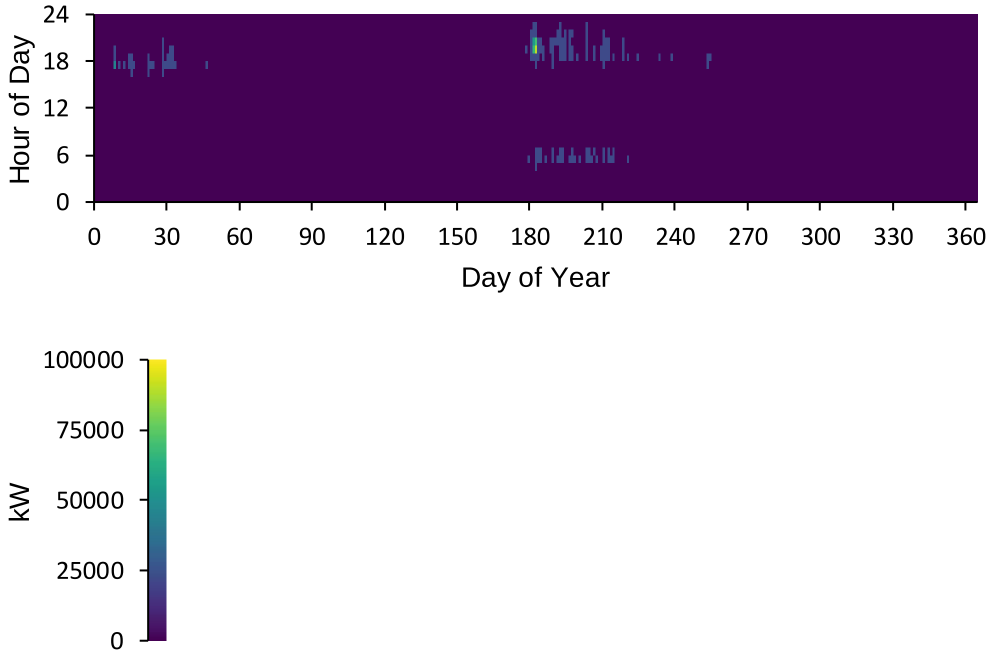

24
18
12
6
0
Hour of Day
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of Year
600000
450000
300000
150000
0
kW

Generator: biomass (Natural Gas)

Power output from the Generic generator system, rated at 90,000 kW using Natural Gas as fuel, is 3,610,660 kWh/yr.

Capacity	90,000 kW
Operational Life	99.3 yr
Capital Cost	€306M
Fuel Consumption	221,520 m³
Hours of Operation	151 hrs/yr
Fixed Generation Cost	21,295 €/hr

Generator Fuel	Natural Gas
Generator Fuel Price	0.300 €/m³
Maintenance Cost	57,984 €/yr
Electrical Production	3,610,660 kWh/yr
Marginal Generation Cost	0.0989 €/kWh



Grid

The annual energy purchased from the grid is 2,586,987,520 kWh and the annual energy sold to the grid is 2,961,475,072 kWh.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	275,971,648	185,110,384	90,861,264	1,000,000	€15.6M	€0.00	€15.6M
February	202,220,240	208,090,944	-5,870,705	982,883	€7.80M	€0.00	€7.80M
March	174,538,944	270,466,752	-95,927,816	853,500	€2.19M	€0.00	€2.19M
April	146,234,880	288,466,976	-142,232,080	687,995	-€1.26M	€0.00	-€1.26M
May	161,063,056	303,864,672	-142,801,616	657,497	-€697,558	€0.00	-€697,558
June	182,985,984	287,208,128	-104,222,136	889,042	€2.11M	€0.00	€2.11M
July	286,822,560	246,236,320	40,586,232	1,000,000	€13.5M	€0.00	€13.5M
August	273,063,936	270,579,008	2,484,945	976,941	€11.0M	€0.00	€11.0M
September	241,174,576	257,837,632	-16,663,044	928,924	€8.81M	€0.00	€8.81M
October	211,848,944	259,995,040	-48,146,092	774,230	€6.07M	€0.00	€6.07M
November	188,724,528	202,622,528	-13,898,011	806,470	€6.85M	€0.00	€6.85M
December	242,338,352	180,996,800	61,341,552	885,048	€12.8M	€0.00	€12.8M
Annual	2,586,987,520	2,961,475,072	-374,487,520	1,000,000	€84.8M	€0.00	€84.8M

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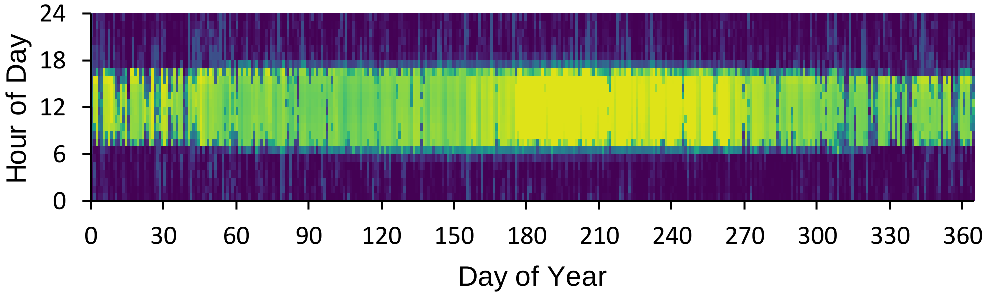
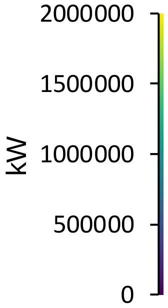
Converter: System Converter

Capacity	1,912,582 kW
Mean Output	730,795 kW
Minimum Output	0 kW
Maximum Output	1,912,582 kW
Capacity Factor	38.2 %

Hours of Operation	8,122 hrs/yr
Energy Out	6,401,763,840 kWh/yr
Energy In	6,738,698,752 kWh/yr
Losses	336,934,944 kWh/yr





Cash Flows

Project Lifetime 25 years

Expected Inflation Rate 2.0%

Nominal Discount Rate 8.0%

Real Interest Rate 5.9%

Year	1	2	3	4	5	6	7	8	9	10
ABB PowerStore Flywheel	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00
biomass	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)
Grid	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)
Peimar SG300MBF	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)
System Converter	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00
Vestas V90-2.0	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)

Year	11	12	13	14	15	16	17	18	19	20
ABB PowerStore Flywheel	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	(€6,000)
biomass	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)
Grid	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)
Peimar SG300MBF	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)
System Converter	€0.00	€0.00	€0.00	€0.00	(€574M)	€0.00	€0.00	€0.00	€0.00	€0.00
Vestas V90-2.0	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)

Year	21	22	23	24	25
ABB PowerStore Flywheel	€0.00	€0.00	€0.00	€0.00	€4,500
biomass	(€57,984)	(€57,984)	(€57,984)	(€57,984)	(€57,984)
Grid	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)	(€84.8M)
Peimar SG300MBF	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)	(€21.0M)
System Converter	€0.00	€0.00	€0.00	€0.00	€191M
Vestas V90-2.0	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)	(€15.7M)

Glossary and Abbreviations

Net Present Value

The total net present cost (NPC) of a system is the present value of all the costs the system incurs over its lifetime, minus the present value of all the revenue it earns over its lifetime. Costs include capital costs, replacement costs, O & M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue. HOMER calculates the total NPC by summing the total discounted cash flows in each year of the project lifetime.

Total Annualized Cost

- is the annualized value of the total net present cost. The annualized cost of a component is the cost that, if it were to occur equally in every year of the project lifetime, would give the same net present cost as the actual cash flow sequence associated with that component. HOMER calculates annualized cost by first calculating the net present cost, then multiplying it by the capital recovery factor.

Simple payback

- is the number of years at which the cumulative cash flow of the difference between the current system and base case system switches from negative to positive. The payback is an indication of how long it would take to recover the difference in investment costs between the current system and the base case system.

Return on Investment (ROI)

- is the yearly cost savings relative to the initial investment. The ROI is the average yearly difference in nominal cash flows over the project lifetime, divided by the difference in capital cost.

Internal rate of return (IRR)

- is the discount rate at which the base case and current system have the same net present cost. HOMER calculates the IRR by determining the discount rate that makes the present value of the difference of the two cash flow sequences equal to zero.

Refer to HOMER Pro Online Help Manual

Abbreviations

GenLarge (12)	biomass
1kWh LA	Generic 1kWh Lead Acid
ABB-PS	ABB PowerStore Flywheel
Ves2000	Vestas V90-2.0
SG300MBF	Peimar SG300MBF
Converter	System Converter

About HOMER Pro

HOMER® Pro simulates engineering and economic feasibility of microgrid or distributed energy systems that are off-grid or tied to an unreliable grid and enables the design of least-cost electrical systems and risk-mitigation strategies. The software provides insight into cost-effectively combining conventional and renewable energy, storage, grid resources (where available), and load management.

In a single data run, HOMER Pro simulates the operation of a hybrid microgrid or distributed energy system for an entire year, evaluating and optimizing the electrical system design, load profiles, components, fuel costs, and environmental variables. The simulation produces key information on technical performance, risk-mitigation, and projected cost-savings to inform system design and optimization. Results are presented in a succinct Microgrid Proposal. For more information, visit HomerEnergy.com.

About HOMER Energy by UL

HOMER software is used by more than 200,000 users in 193 different countries.

HOMER Energy by UL is the developer and distributor of HOMER software, a global standard for energy modeling tools that analyze solar-plus-storage, microgrids, and other distributed energy projects.

HOMER software helps engineers and project developers navigate the complexities of designing cost-effective and reliable microgrids that combine traditional and renewable generation sources. The company makes two software platforms: HOMER Pro for the design of least-cost hybrid microgrid or distributed energy systems for use off-grid or when tied to an unreliable grid; and HOMER Grid, which helps design behind-the-meter solar-plus-storage systems to reduce costs and lower carbon footprints.

Since its founding in Boulder, Colorado in 2009, HOMER Energy software has proven effective for analyzing complex distributed energy systems, including grid-tied hybrid renewable microgrids and situations where the grid is insufficiently reliable, such as islands and remote communities. In 2019, HOMER Energy was acquired by UL. More than 200,000 HOMER Pro users in over 190 countries have produced economic feasibility studies, system design, engineering insight, and energy cost savings. Learn more at www.homerenergy.com.

Microgrid Proposal

PREPARED FOR:
NAS_VRFB_R3p, NAS_VRFB_R3p
Unnamed Road, Lefkoşa 99040

PREPARED BY:
Your Name, Your Title
Your Company Name, Your Email
Your Phone Number

This proposal was generated using HOMER Pro, a dynamic software engine that runs complex simulations of your hybrid electrical system's energy data and system components to determine the least-cost solution and most effective risk-mitigation strategies. Originally developed at the US Department of Energy's National Renewable Energy Laboratory (NREL), HOMER software set the global standard for optimizing microgrid design. More than 200,000 HOMER Pro users worldwide have produced economic feasibility studies, system design, engineering insight, and energy cost savings.

Table of Contents

PREPARED BY:
Your Name,
Your Title, Your Company Name,
Your Email,
Your Phone Number

Project Summary

CURRENT SYSTEM

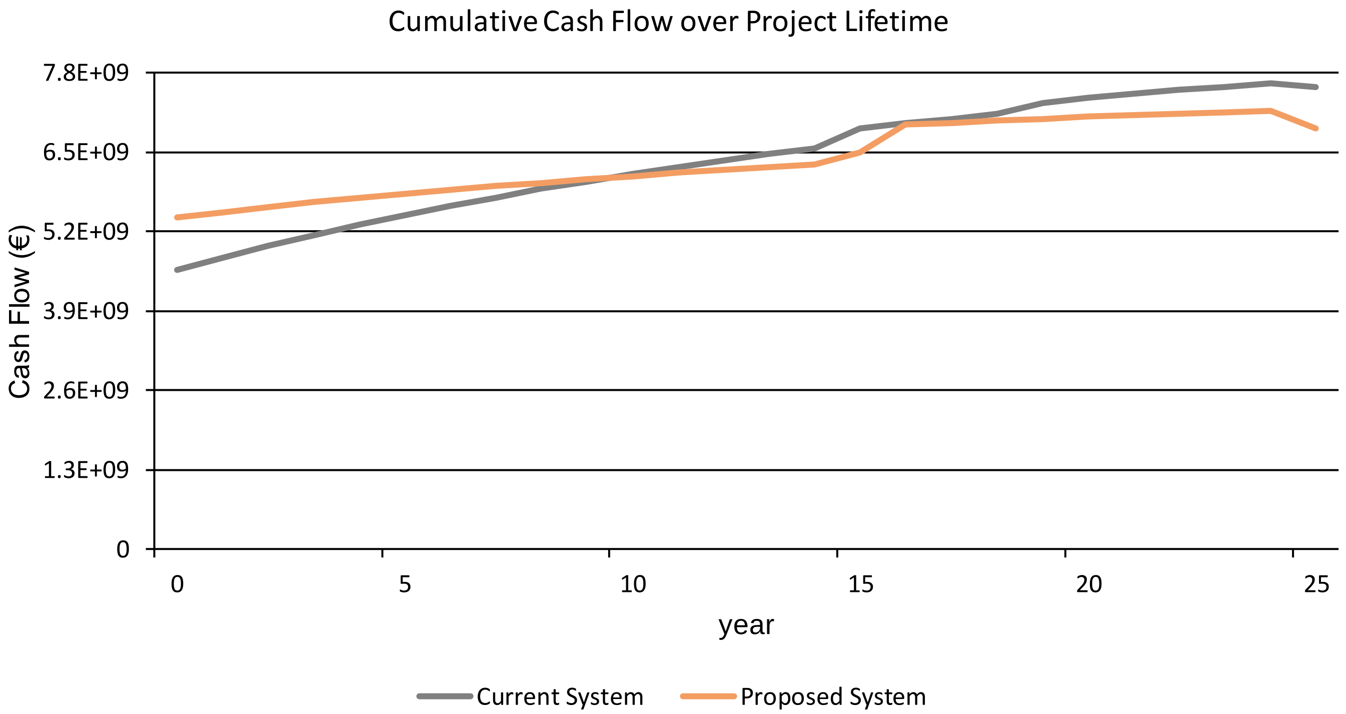
The electric needs of Unnamed Road, Lefkoşa 99040 are met with 90,000 kW of generator capacity, 16,215,012 kWh of battery capacity and 3,708,000 kW of wind generation capacity. Your operating costs for energy are currently €232M per year.

PROPOSED SYSTEM

We propose adding 4,770,191 kW of PV. This would reduce your operating costs to €113M/yr. Your investment has a payback of 7.11 years and an IRR of 12.7%.

Simple payback:	7.11 yr
Return on Investment:	11.8 %
Internal Rate of Return:	12.7 %

Net Present Value:	€684M
Capital Investment:	€860M
Annualized Savings:	€119M



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ABOUT YOUR COMPANY NAME

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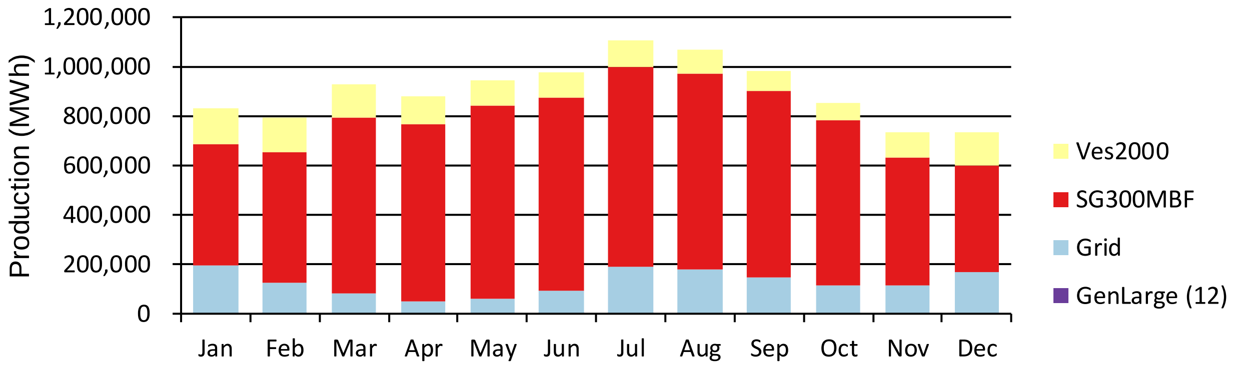
—John J. Client, CEO - Your Happy Client, Inc.

Consumption Summary

Electric Consumption

This microgrid requires 20811901 kWh/day and has a peak of 1372952 kW. In the proposed system, the following generation sources serve the electrical load.



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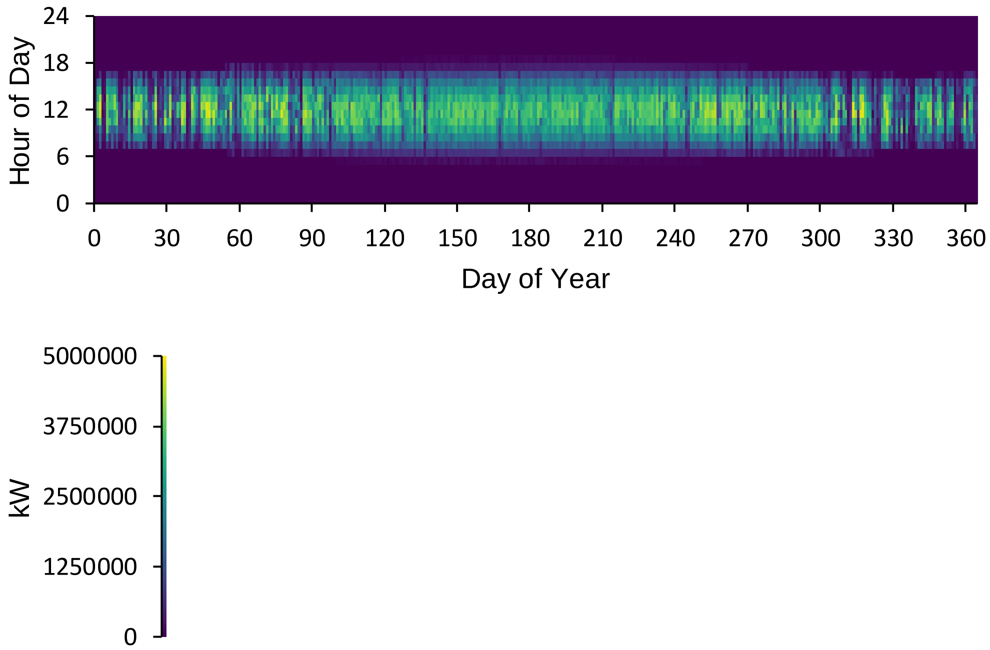
Engineering Details

PV: Peimar SG300MBF

The Peimar Inc. PV system has a nominal capacity of 4,770,191 kW. The annual production is 7,977,070,592 kWh/yr.

Rated Capacity	4,770,191 kW
Capital Cost	€3.10B
Specific Yield	1,672 kWh/kW
PV Penetration	132 %

Total Production	7,977,070,592 kW
Maintenance Cost	16,218,649 €/yr
LCOE	0.0309 €/kWh

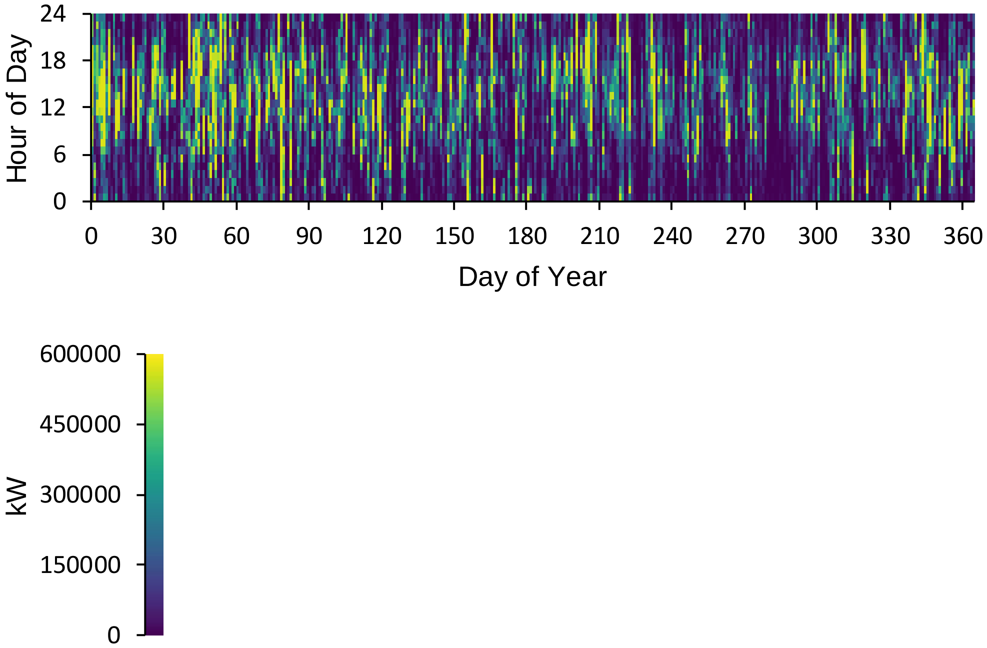


Wind Turbine: Vestas V90-2.0

Power output from the Vestas wind turbine system, rated at 572,000 kW, is 1,340,076,544 kWh/yr.

Quantity	286
Wind Turbine Total Production	1,340,076,544 kWh/yr
Capital Cost	€572M
Wind Turbine Lifetime	20.0 years

Rated Capacity	572,000 kW
Hours of Operation	7,837 hrs/yr
Maintenance Cost	16,845,400 €/yr



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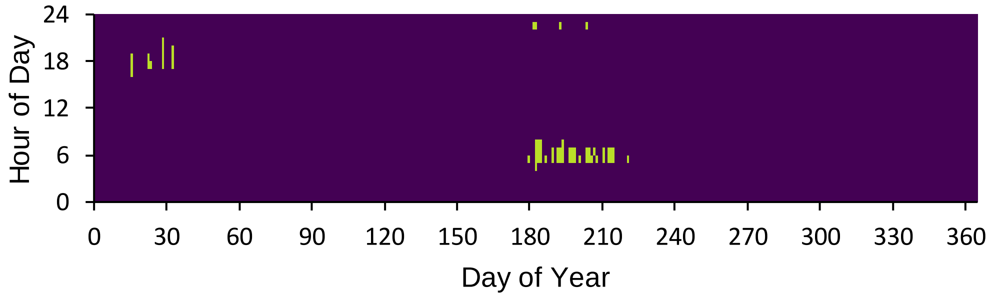
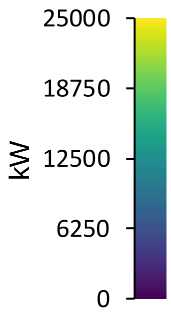
Generator: biomass (Natural Gas)

Power output from the Generic generator system, rated at 90,000 kW using Natural Gas as fuel, is 1,372,500 kWh/yr.

Capacity	90,000 kW	Generator Fuel	Natural Gas
Operational Life	246 yr	Generator Fuel Price	0.300 €/m³
Capital Cost	€306M	Maintenance Cost	23,424 €/yr
Fuel Consumption	82,350 m³	Electrical Production	1,372,500 kWh/yr
Hours of Operation	61.0 hrs/yr	Marginal Generation Cost	0.0989 €/kWh
Fixed Generation Cost	21,295 €/hr		





Storage: UET Reflex Product V7

The UET storage system's nominal capacity is 3,842,254 kWh. The annual throughput is 1,260,153,216 kWh/yr.

Rated Capacity	3,842,254 kWh	Expected Life	15.2 yr
Annual Throughput	1,260,153,216 kWh/yr	Capital Costs	€1.04B
Maintenance Cost	72,546 €/yr	Losses	204,698,960 kWh/yr
Autonomy	5.58 hr		

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Your Email,
Your Phone Number

Grid

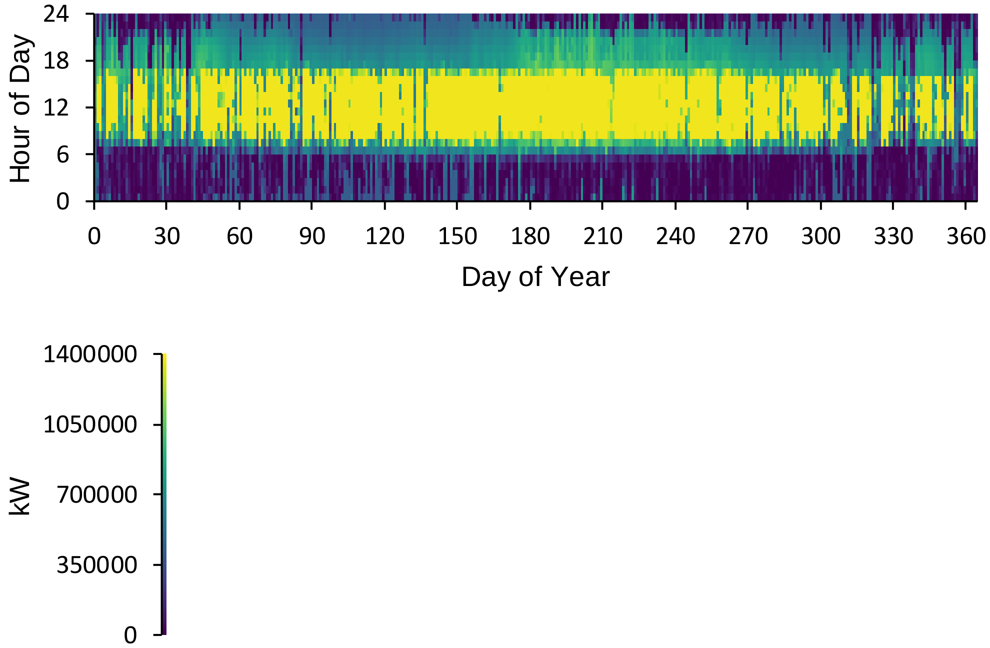
The annual energy purchased from the grid is 1,516,978,688 kWh and the annual energy sold to the grid is 1,568,914,432 kWh.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	196,069,872	80,212,752	115,857,120	980,012	€13.6M	€0.00	€13.6M
February	123,748,600	112,662,512	11,086,092	943,169	€5.50M	€0.00	€5.50M
March	80,441,912	174,003,856	-93,561,952	784,205	-€1.46M	€0.00	-€1.46M
April	51,580,844	198,930,368	-147,349,520	607,687	-€5.30M	€0.00	-€5.30M
May	60,457,656	191,884,000	-131,426,344	602,479	-€4.15M	€0.00	-€4.15M
June	91,230,656	152,101,376	-60,870,720	880,808	€605,690	€0.00	€605,690
July	190,766,720	78,406,936	112,359,776	933,902	€13.2M	€0.00	€13.2M
August	176,838,944	107,087,848	69,751,096	877,250	€10.6M	€0.00	€10.6M
September	147,566,080	110,742,128	36,823,960	865,958	€7.74M	€0.00	€7.74M
October	115,254,280	149,000,432	-33,746,148	723,352	€2.92M	€0.00	€2.92M
November	117,131,808	118,229,296	-1,097,485	700,391	€4.63M	€0.00	€4.63M
December	165,891,376	95,652,920	70,238,448	825,005	€10.1M	€0.00	€10.1M
Annual	1,516,978,688	1,568,914,432	-51,935,672	980,012	€58.1M	€0.00	€58.1M

Converter: System Converter

Capacity	1,372,952 kW
Mean Output	694,206 kW
Minimum Output	0 kW
Maximum Output	1,372,952 kW
Capacity Factor	50.6 %

Hours of Operation	8,326 hrs/yr
Energy Out	6,081,245,184 kWh/yr
Energy In	6,401,310,720 kWh/yr
Losses	320,065,536 kWh/yr



Cash Flows

Project Lifetime	25 years	Expected Inflation Rate	2.0%
Nominal Discount Rate	8.0%	Real Interest Rate	5.9%

Year	1	2	3	4	5	6	7	8	9	10
BASF NAS® Battery	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)
biomass	(€23,424)	(€23,424)	(€23,424)	(€23,424)	(€23,424)	(€23,424)	(€23,424)	(€23,424)	(€23,424)	(€23,424)
Grid	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)
Peimar SG300MBF	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)
System Converter	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00
Vestas V90-2.0	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)

Year	11	12	13	14	15	16	17	18	19	20
BASF NAS® Battery	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)
biomass	(€23,424)	(€23,424)	(€23,424)	(€23,424)	(€23,424)	(€23,424)	(€23,424)	(€23,424)	(€23,424)	(€23,424)
Grid	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)	(€58.1M)
Peimar SG300MBF	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)
System Converter	€0.00	€0.00	€0.00	€0.00	(€412M)	€0.00	€0.00	€0.00	€0.00	€0.00
Vestas V90-2.0	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)

Year	21	22	23	24	25
BASF NAS® Battery	(€72,546)	(€72,546)	(€72,546)	(€72,546)	(€72,546)
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Peimar SG300MBF	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)	(€16.2M)
System Converter	€0.00	€0.00	€0.00	€0.00	€137M
Vestas V90-2.0	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)	(€16.8M)

Net Present Value
The total net present cost (NPC) of a system is the present value of all the costs the system incurs over its lifetime, minus the present value of all the revenue it earns over its lifetime. Costs include capital costs, replacement costs, O & M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue. HOMER calculates the total NPC by summing the total discounted cash flows in each year of the project lifetime.

Total Annualized Cost
- is the annualized value of the total net present cost. The annualized cost of a component is the cost that, if it were to occur equally in every year of the project lifetime, would give the same net present cost as the actual cash flow sequence associated with that component. HOMER calculates annualized cost by first calculating the net present cost, then multiplying it by the capital recovery factor.

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- is the number of years at which the cumulative cash flow of the difference between the current system and base case system switches from negative to positive. The payback is an indication of how long it would take to recover the difference in investment costs between the current system and the base case system.

Return on Investment (ROI)
- is the yearly cost savings relative to the initial investment. The ROI is the average yearly difference in nominal cash flows over the project lifetime, divided by the difference in capital cost.

Internal rate of return (IRR)
- is the discount rate at which the base case and current system have the same net present cost. HOMER calculates the IRR by determining the discount rate that makes the present value of the difference of the two cash flow sequences equal to zero.

Refer to HOMER Pro Online Help Manual

Abbreviations

GenLarge (12)	biomass
UET Reflex	UET Reflex Product V7
NAS® Battery	BASF NAS® Battery
Ves2000	Vestas V90-2.0
SG300MBF	Peimar SG300MBF
Converter	System Converter

PREPARED BY:
Your Name,
Your Title, Your Company Name,
Your Email,
Your Phone Number

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Microgrid Proposal

PREPARED FOR:
NAS_VRFB_R3o, NAS_VRFB_R3o
Unnamed Road, Lefkoşa 99040

PREPARED BY:
Your Name, Your Title
Your Company Name, Your Email
Your Phone Number

This proposal was generated using HOMER Pro, a dynamic software engine that runs complex simulations of your hybrid electrical system's energy data and system components to determine the least-cost solution and most effective risk-mitigation strategies. Originally developed at the US Department of Energy's National Renewable Energy Laboratory (NREL), HOMER software set the global standard for optimizing microgrid design. More than 200,000 HOMER Pro users worldwide have produced economic feasibility studies, system design, engineering insight, and energy cost savings.

Table of Contents

PREPARED BY:

Your Name,

Your Title, Your Company Name,

Your Email,

Your Phone Number

Project Summary

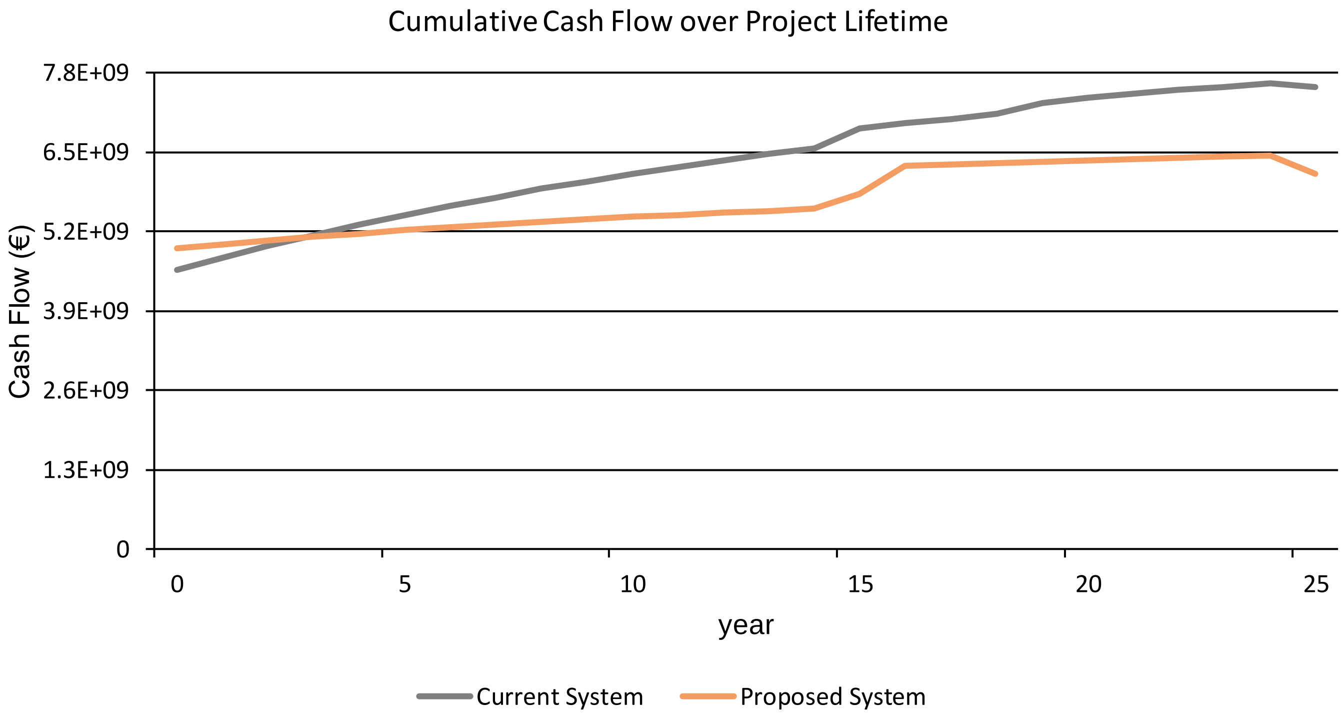
CURRENT SYSTEM

The electric needs of Unnamed Road, Lefkoşa 99040 are met with 90,000 kW of generator capacity, 16,215,012 kWh of battery capacity and 3,708,000 kW of wind generation capacity. Your operating costs for energy are currently €232M per year.

PROPOSED SYSTEM

We propose adding 3,594,966 kW of PV. This would reduce your operating costs to €94.8M/yr. Your investment has a payback of 2.47 years and an IRR of 40.1%.

Simple payback:	2.47 yr		Net Present Value:	€1.42B
Return on Investment:	38.8 %		Capital Investment:	€354M
Internal Rate of Return:	40.1 %		Annualized Savings:	€138M



ABOUT YOUR COMPANY NAME

Use this section to introduce your company name and explain what your business does, where you operate (or the markets you serve), and how long you've been doing it for. About Us page is the ideal place to accommodate several objectives:

- Communicate the story of your business and why you started it.
- Describe the customers or the cause that your business serves.
- Explain your business model or how your products are made

Customer Testimonials

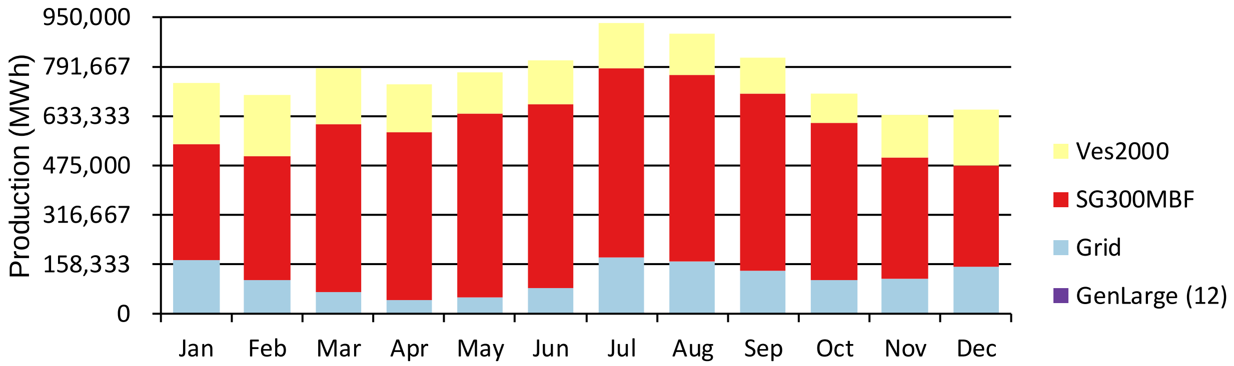
Use this space to provide statements made about your company by satisfied customers. Quotes and positive comments are valuable to prospective clients as they evaluate their options and decide whether your company's services provide the best solution to fit their needs. Testimonial statements demonstrate how others have benefited from your company's services, making them a powerful tool for establishing trust and encouraging potential clients to take action.

—John J. Client, CEO - Your Happy Client, Inc.

Consumption Summary

Electric Consumption

This microgrid requires 21456734 kWh/day and has a peak of 1705118 kW. In the proposed system, the following generation sources serve the electrical load.



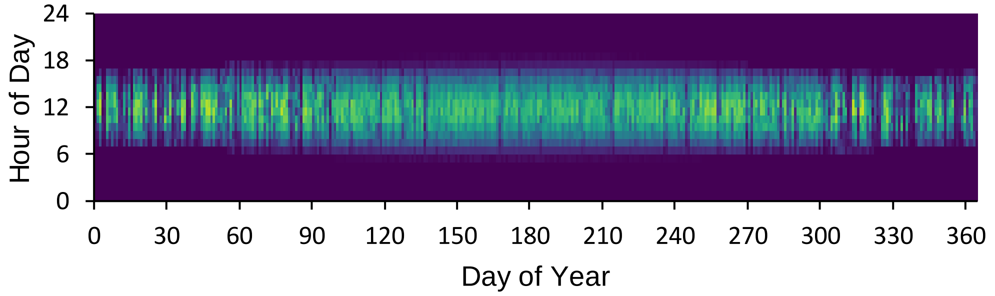
Engineering Details

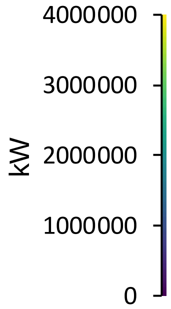
PV: Peimar SG300MBF

The Peimar Inc. PV system has a nominal capacity of 3,594,966 kW. The annual production is 6,011,770,880 kWh/yr.

Rated Capacity	3,594,966 kW
Capital Cost	€2.34B
Specific Yield	1,672 kWh/kW
PV Penetration	99.7 %

Total Production	6,011,770,880 kW
Maintenance Cost	12,222,884 €/yr
LCOE	0.0309 €/kWh



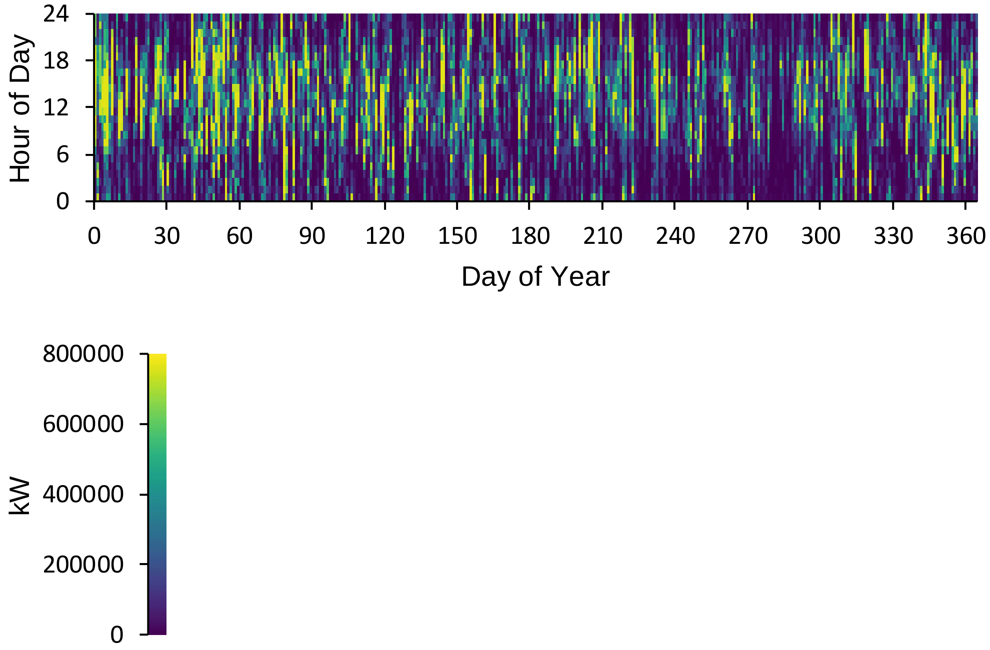


Wind Turbine: Vestas V90-2.0

Power output from the Vestas wind turbine system, rated at 768,000 kW, is 1,799,263,616 kWh/yr.

Quantity	384
Wind Turbine Total Production	1,799,263,616 kWh/yr
Capital Cost	€768M
Wind Turbine Lifetime	20.0 years

Rated Capacity	768,000 kW
Hours of Operation	7,837 hrs/yr
Maintenance Cost	22,617,600 €/yr


24
18
12
6
0
Hour of Day
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of Year
800000
600000
400000
200000
0
kW

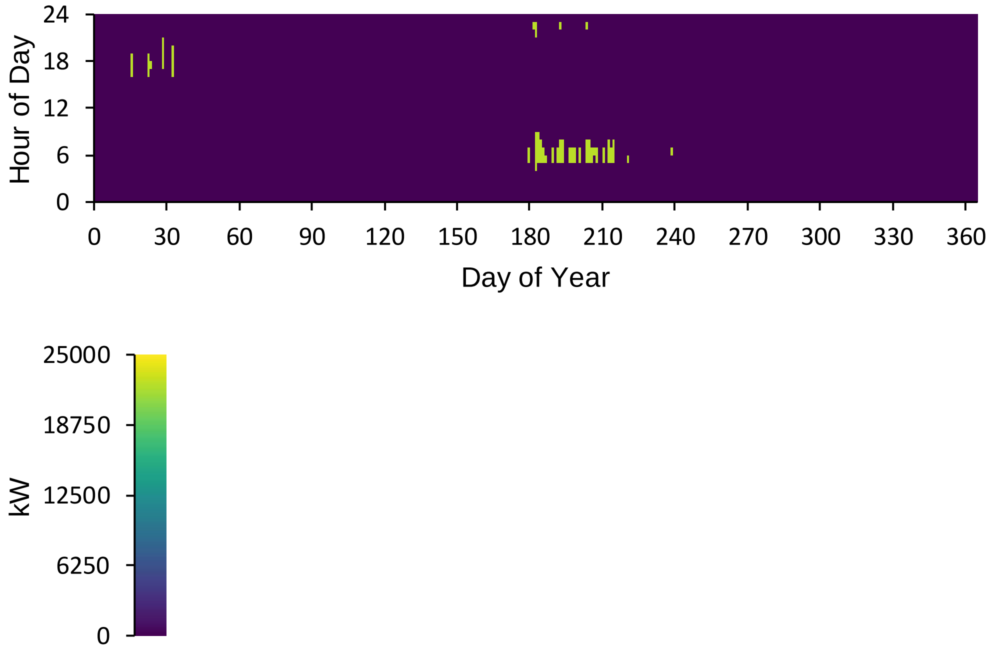
Engineering Details

Generator: biomass (Natural Gas)

Power output from the Generic generator system, rated at 90,000 kW using Natural Gas as fuel, is 1,755,000 kWh/yr.

Capacity	90,000 kW
Operational Life	192 yr
Capital Cost	€306M
Fuel Consumption	105,300 m^3
Hours of Operation	78.0 hrs/yr
Fixed Generation Cost	21,295 €/hr

Generator Fuel	Natural Gas
Generator Fuel Price	0.300 €/m^3
Maintenance Cost	29,952 €/yr
Electrical Production	1,755,000 kWh/yr
Marginal Generation Cost	0.0989 €/kWh



Storage: UET Reflex Product V7

The UET storage system's nominal capacity is 4,177,233 kWh. The annual throughput is 1,307,453,568 kWh/yr.

Rated Capacity	4,177,233 kWh
Annual Throughput	1,307,453,568 kWh/yr
Maintenance Cost	78,871 €/yr
Autonomy	6.07 hr

Expected Life	16.0 yr
Capital Costs	€1.00B
Losses	212,366,272 kWh/yr

Grid

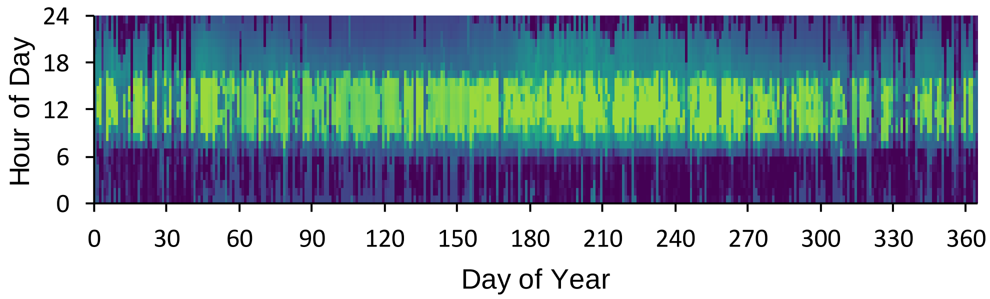
The annual energy purchased from the grid is 1,376,247,680 kWh and the annual energy sold to the grid is 1,803,981,440 kWh.

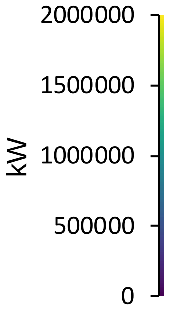
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	172,831,504	98,000,576	74,830,928	955,283	€10.7M	€0.00	€10.7M
February	108,016,552	132,165,304	-24,148,756	935,661	€3.11M	€0.00	€3.11M
March	68,735,064	186,854,576	-118,119,512	777,881	-€3.16M	€0.00	-€3.16M
April	41,831,884	207,808,320	-165,976,432	611,331	-€6.63M	€0.00	-€6.63M
May	52,166,424	212,883,424	-160,717,008	598,168	-€5.95M	€0.00	-€5.95M
June	82,769,264	181,919,360	-99,150,088	880,036	-€1.65M	€0.00	-€1.65M
July	177,052,000	114,007,840	63,044,168	983,614	€10.2M	€0.00	€10.2M
August	166,660,336	138,077,408	28,582,938	882,707	€8.10M	€0.00	€8.10M
September	139,559,616	140,096,080	-536,473	889,760	€5.56M	€0.00	€5.56M
October	106,540,600	157,283,344	-50,742,740	719,594	€1.72M	€0.00	€1.72M
November	111,273,392	131,795,264	-20,521,874	725,792	€3.42M	€0.00	€3.42M
December	148,811,056	103,089,920	45,721,132	850,730	€8.24M	€0.00	€8.24M
Annual	1,376,247,680	1,803,981,440	-427,733,728	983,614	€33.7M	€0.00	€33.7M

Converter: System Converter

Capacity	1,705,118 kW
Mean Output	737,062 kW
Minimum Output	0 kW
Maximum Output	1,705,118 kW
Capacity Factor	43.2 %

Hours of Operation	8,348 hrs/yr
Energy Out	6,456,660,480 kWh/yr
Energy In	6,796,484,608 kWh/yr
Losses	339,824,256 kWh/yr




2000000
1500000
1000000
500000
0
kW

Cash Flows

Project Lifetime 25 years

Expected Inflation Rate 2.0%

Nominal Discount Rate 8.0%

Real Interest Rate 5.9%

Year	1	2	3	4	5	6	7	8	9	10
BASF NAS® Battery	(€78,871)	(€78,871)	(€78,871)	(€78,871)	(€78,871)	(€78,871)	(€78,871)	(€78,871)	(€78,871)	(€78,871)
biomass	(€29,952)	(€29,952)	(€29,952)	(€29,952)	(€29,952)	(€29,952)	(€29,952)	(€29,952)	(€29,952)	(€29,952)
Grid	(€33.7M)	(€33.7M)	(€33.7M)	(€33.7M)	(€33.7M)	(€33.7M)	(€33.7M)	(€33.7M)	(€33.7M)	(€33.7M)
Peimar SG300MBF	(€12.2M)	(€12.2M)	(€12.2M)	(€12.2M)	(€12.2M)	(€12.2M)	(€12.2M)	(€12.2M)	(€12.2M)	(€12.2M)
System Converter	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00
Vestas V90-2.0	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)

Year	11	12	13	14	15	16	17	18	19	20
BASF NAS® Battery	(€78,871)	(€78,871)	(€78,871)	(€78,871)	(€78,871)	(€78,871)	(€78,871)	(€78,871)	(€78,871)	(€78,871)
biomass	(€29,952)	(€29,952)	(€29,952)	(€29,952)	(€29,952)	(€29,952)	(€29,952)	(€29,952)	(€29,952)	(€29,952)
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System Converter	€0.00	€0.00	€0.00	€0.00	(€512M)	€0.00	€0.00	€0.00	€0.00	€0.00
Vestas V90-2.0	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)

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System Converter	€0.00	€0.00	€0.00	€0.00	€171M
Vestas V90-2.0	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)	(€22.6M)

Glossary and Abbreviations

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PREPARED BY:
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Microgrid Proposal

PREPARED FOR:
NAS_VRFB_R3e, NAS_VRFB_R3e
Unnamed Road, Lefkoşa 99040

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HOMER Pro

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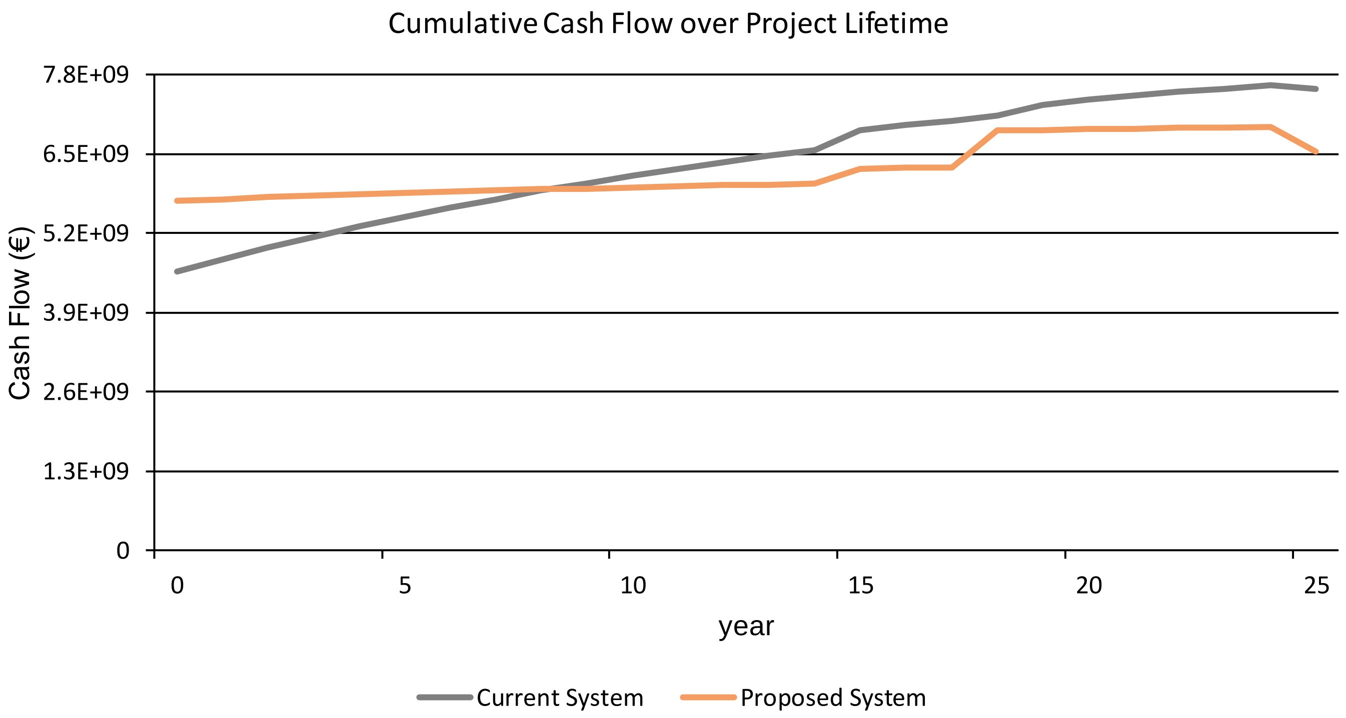
PROPOSED SYSTEM

We propose adding 3,888,852 kW of PV. This would reduce your operating costs to €62.4M/yr. Your investment has a payback of 6.36 years and an IRR of 14.3%.

Simple payback:	6.36 yr
Return on Investment:	12.0 %
Internal Rate of Return:	14.3 %

Net Present Value:	€1.04B
Capital Investment:	€1.16B
Annualized Savings:	€170M



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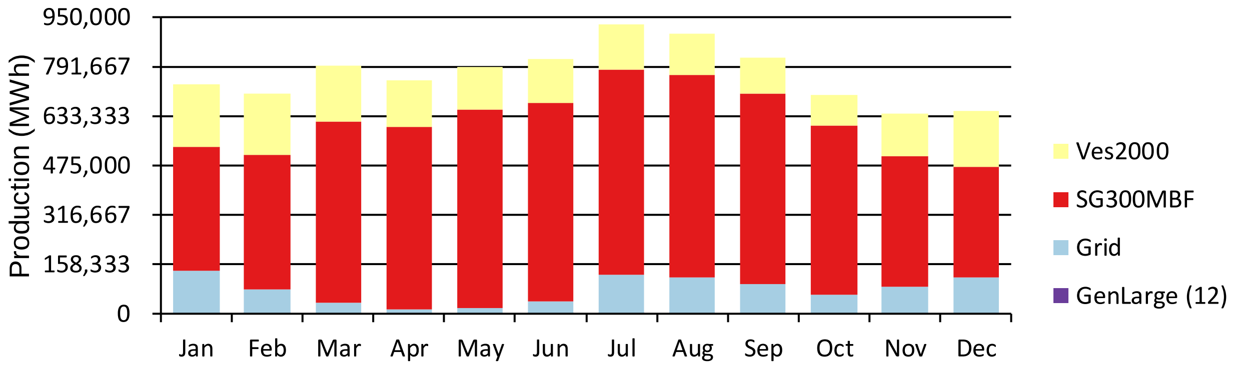
—John J. Client, CEO - Your Happy Client, Inc.

Consumption Summary

Electric Consumption

This microgrid requires 21379490 kWh/day and has a peak of 1872029 kW. In the proposed system, the following generation sources serve the electrical load.

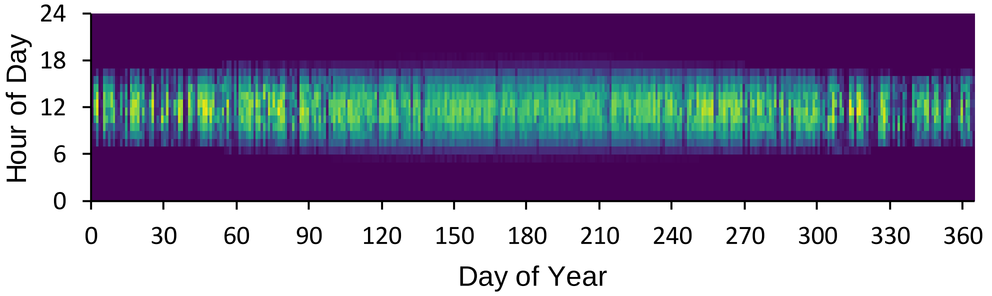


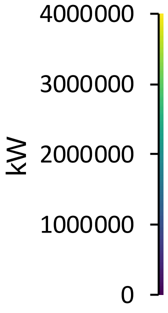
Engineering Details

PV: Peimar SG300MBF

The Peimar Inc. PV system has a nominal capacity of 3,888,852 kW. The annual production is 6,503,229,440 kWh/yr.

Rated Capacity	3,888,852 kW	Total Production	6,503,229,440 kW
Capital Cost	€2.53B	Maintenance Cost	13,222,097 €/yr
Specific Yield	1,672 kWh/kW	LCOE	0.0309 €/kWh
PV Penetration	108 %		





Wind Turbine: Vestas V90-2.0

Power output from the Vestas wind turbine system, rated at 770,000 kW, is 1,803,949,184 kWh/yr.

Quantity	385	Rated Capacity	770,000 kW
Wind Turbine Total Production	1,803,949,184 kWh/yr	Hours of Operation	7,837 hrs/yr
Capital Cost	€770M	Maintenance Cost	22,676,500 €/yr
Wind Turbine Lifetime	20.0 years		

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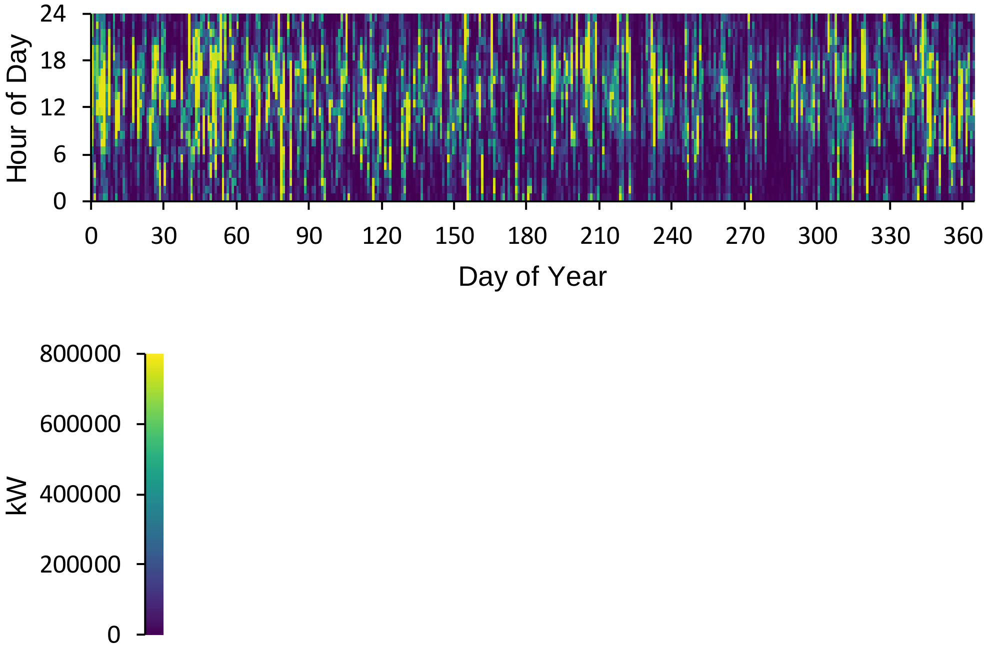
Your Phone Number

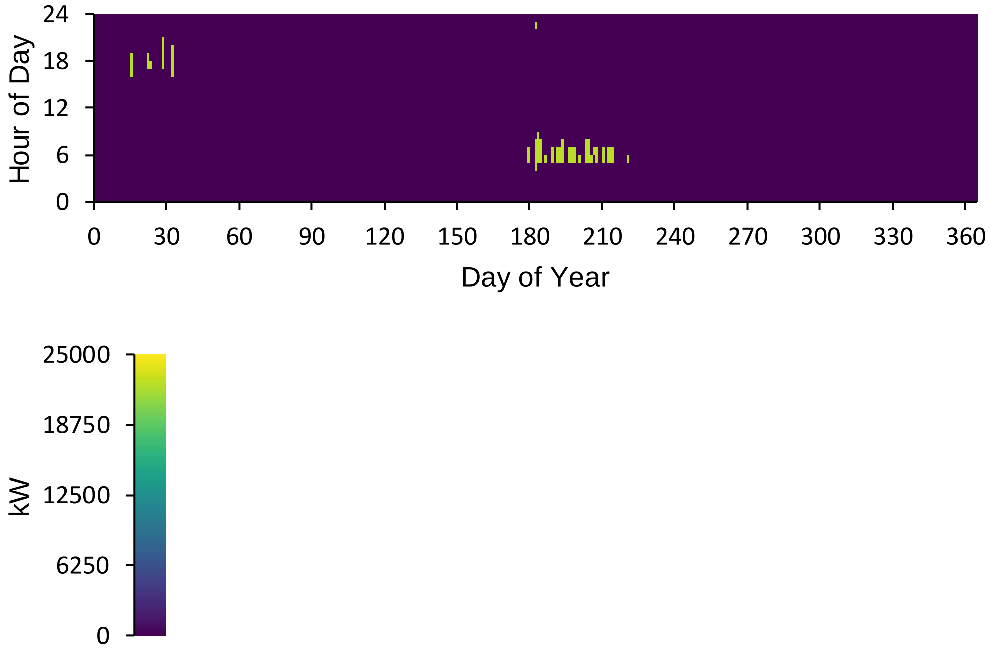

Hour of Day
24
18
12
6
0
0
30
60
90
120
150
180
210
240
270
300
330
360
Day of Year
800000
600000
400000
200000
0
kW

Generator: biomass (Natural Gas)

Power output from the Generic generator system, rated at 90,000 kW using Natural Gas as fuel, is 1,440,000 kWh/yr.

Capacity	90,000 kW
Operational Life	234 yr
Capital Cost	€306M
Fuel Consumption	86,400 m³
Hours of Operation	64.0 hrs/yr
Fixed Generation Cost	21,295 €/hr

Generator Fuel	Natural Gas
Generator Fuel Price	0.300 €/m³
Maintenance Cost	24,576 €/yr
Electrical Production	1,440,000 kWh/yr
Marginal Generation Cost	0.0989 €/kWh



Storage: UET Reflex Product V7

The UET storage system's nominal capacity is 6,134,608 kWh. The annual throughput is 1,804,100,736 kWh/yr.

Rated Capacity	6,134,608 kWh
Annual Throughput	1,804,100,736 kWh/yr
Maintenance Cost	115,829 €/yr
Autonomy	8.91 hr

Expected Life	17.0 yr
Capital Costs	€1.56B
Losses	293,003,968 kWh/yr

Engineering Details

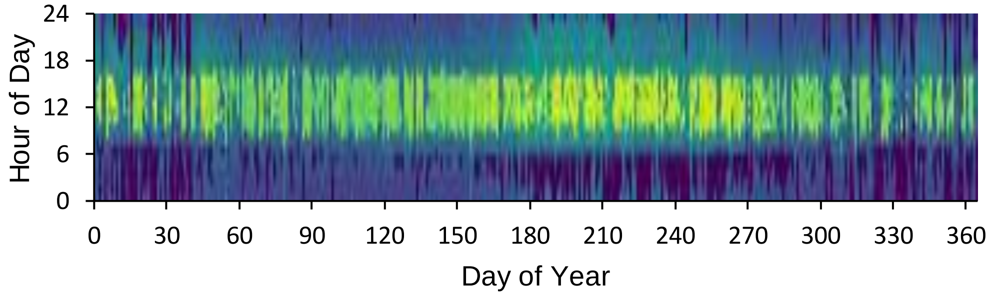
Grid

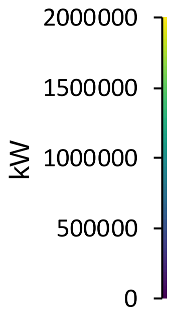
The annual energy purchased from the grid is 916,079,680 kWh and the annual energy sold to the grid is 1,775,690,880 kWh.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge	Demand Charge	Total
January	137,019,632	95,597,192	41,422,436	955,031	€7.55M	€0.00	€7.55M
February	79,109,184	128,411,120	-49,301,936	935,585	€699,271	€0.00	€699,271
March	33,334,852	177,913,280	-144,578,432	777,816	-€5.90M	€0.00	-€5.90M
April	12,237,418	203,657,296	-191,419,888	608,374	-€9.08M	€0.00	-€9.08M
May	17,169,240	204,860,464	-187,691,232	588,260	-€8.70M	€0.00	-€8.70M
June	40,212,688	182,106,304	-141,893,616	865,456	-€5.49M	€0.00	-€5.49M
July	124,118,368	119,366,424	4,751,942	944,367	€5.20M	€0.00	€5.20M
August	117,713,248	146,371,888	-28,658,636	881,042	€3.28M	€0.00	€3.28M
September	93,594,456	147,381,680	-53,787,220	866,980	€1.05M	€0.00	€1.05M
October	59,974,748	147,241,488	-87,266,736	692,780	-€1.96M	€0.00	-€1.96M
November	84,381,448	127,203,120	-42,821,672	725,640	€1.23M	€0.00	€1.23M
December	117,214,376	95,580,584	21,633,788	818,156	€5.77M	€0.00	€5.77M
Annual	916,079,680	1,775,690,880	-859,611,200	955,031	-€6.34M	€0.00	-€6.34M

Converter: System Converter

Capacity	1,872,029 kW	Hours of Operation	8,516 hrs/yr
Mean Output	786,399 kW	Energy Out	6,888,852,992 kWh/yr
Minimum Output	0 kW	Energy In	7,251,424,256 kWh/yr
Maximum Output	1,872,029 kW	Losses	362,571,200 kWh/yr
Capacity Factor	42.0 %		





Cash Flows

Project Lifetime 25 years

Expected Inflation Rate 2.0%

Nominal Discount Rate 8.0%

Real Interest Rate 5.9%

Year	1	2	3	4	5	6	7	8	9	10
BASF NAS® Battery	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)
biomass	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)
Grid	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M
Peimar SG300MBF	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)
System Converter	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00	€0.00
Vestas V90-2.0	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)

Year	11	12	13	14	15	16	17	18	19	20
BASF NAS® Battery	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)
biomass	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)
Grid	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M
Peimar SG300MBF	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)
System Converter	€0.00	€0.00	€0.00	€0.00	(€562M)	€0.00	€0.00	€0.00	€0.00	€0.00
Vestas V90-2.0	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)

Year	21	22	23	24	25
BASF NAS® Battery	(€115,829)	(€115,829)	(€115,829)	(€115,829)	(€115,829)
biomass	(€24,576)	(€24,576)	(€24,576)	(€24,576)	(€24,576)
Grid	€6.34M	€6.34M	€6.34M	€6.34M	€6.34M
Peimar SG300MBF	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)	(€13.2M)
System Converter	€0.00	€0.00	€0.00	€0.00	€187M
Vestas V90-2.0	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)	(€22.7M)

Glossary and Abbreviations

Net Present Value

The total net present cost (NPC) of a system is the present value of all the costs the system incurs over its lifetime, minus the present value of all the revenue it earns over its lifetime. Costs include capital costs, replacement costs, O & M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue. HOMER calculates the total NPC by summing the total discounted cash flows in each year of the project lifetime.

Total Annualized Cost

- is the annualized value of the total net present cost. The annualized cost of a component is the cost that, if it were to occur equally in every year of the project lifetime, would give the same net present cost as the actual cash flow sequence associated with that component. HOMER calculates annualized cost by first calculating the net present cost, then multiplying it by the capital recovery factor.

Simple payback

- is the number of years at which the cumulative cash flow of the difference between the current system and base case system switches from negative to positive. The payback is an indication of how long it would take to recover the difference in investment costs between the current system and the base case system.

Return on Investment (ROI)

- is the yearly cost savings relative to the initial investment. The ROI is the average yearly difference in nominal cash flows over the project lifetime, divided by the difference in capital cost.

Internal rate of return (IRR)

- is the discount rate at which the base case and current system have the same net present cost. HOMER calculates the IRR by determining the discount rate that makes the present value of the difference of the two cash flow sequences equal to zero.

Refer to HOMER Pro Online Help Manual

Abbreviations

GenLarge (12)	biomass
UET Reflex	UET Reflex Product V7
NAS® Battery	BASF NAS® Battery
Ves2000	Vestas V90-2.0
SG300MBF	Peimar SG300MBF
Converter	System Converter

About HOMER Pro

HOMER® Pro simulates engineering and economic feasibility of microgrid or distributed energy systems that are off-grid or tied to an unreliable grid and enables the design of least-cost electrical systems and risk-mitigation strategies. The software provides insight into cost-effectively combining conventional and renewable energy, storage, grid resources (where available), and load management.

In a single data run, HOMER Pro simulates the operation of a hybrid microgrid or distributed energy system for an entire year, evaluating and optimizing the electrical system design, load profiles, components, fuel costs, and environmental variables. The simulation produces key information on technical performance, risk-mitigation, and projected cost-savings to inform system design and optimization. Results are presented in a succinct Microgrid Proposal. For more information, visit HomerEnergy.com.

About HOMER Energy by UL

HOMER software is used by more than 200,000 users in 193 different countries.

HOMER Energy by UL is the developer and distributor of HOMER software, a global standard for energy modeling tools that analyze solar-plus-storage, microgrids, and other distributed energy projects.

HOMER software helps engineers and project developers navigate the complexities of designing cost-effective and reliable microgrids that combine traditional and renewable generation sources. The company makes two software platforms: HOMER Pro for the design of least-cost hybrid microgrid or distributed energy systems for use off-grid or when tied to an unreliable grid; and HOMER Grid, which helps design behind-the-meter solar-plus-storage systems to reduce costs and lower carbon footprints.

Since its founding in Boulder, Colorado in 2009, HOMER Energy software has proven effective for analyzing complex distributed energy systems, including grid-tied hybrid renewable microgrids and situations where the grid is insufficiently reliable, such as islands and remote communities. In 2019, HOMER Energy was acquired by UL. More than 200,000 HOMER Pro users in over 190 countries have produced economic feasibility studies, system design, engineering insight, and energy cost savings. Learn more at www.homerenergy.com.

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Your Title, Your Company Name,
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